THE EFFECTS OF HEMISPACE ON TACHISTOSCOPICALLY PRESENTED VERBAL AND NONVERBAL MATERIAL

BY

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Lateral asymmetries between the functions of the two hemispheres have been investigated over the last twenty years using techniques designed to deliver stimuli initially to either the left or right brain. In the visual modality, tachistoscopic presentation of stimuli to the left visual field (LVF) or right visual field (RVF) accomplishes this effect. The research findings supported the notion of a left hemispheric dominance for verbal processing and a right hemispheric dominance for nonverbal or visuo-spatial processing (in right handers).

There have been several explanations for this phenomenon. The Direct Pathway Transmission model proposes that observed asymmetries stem from a direct anatomical connection between the sensory input channel and the contralateral hemisphere which is specialized to process a particular type of stimulus. Therefore, a RVF advantage is observed for verbal information because RVF input passes along a direct anatomical pathway to the contralateral left hemisphere, which is specialized for verbal processing.

The concept of a hemispatial mechanism has recently challenged this model. Hemispace may be defined as an egocentric coordinate system where the median plane of the body acts as the axis for dividing external space into left and right quadrants. The Hemispatial model states that it is the hemispatial-target hemisphere relationship which is crucial. That is, each hemisphere attends and responds best to stimuli which occur in contralateral hemispace. It argues that the RVF advantage for verbal information is attributable to the fact that the RVF, in past research, has corresponded with right hemispace.

This research attempted to investigate these two models by disentangling the one-to-one correspondence between the visual half fields (VHFs) and hemispatial location. In Experiment I subjects performed a tachistoscopically presented verbal task in left, right, and central hemispatial locations. The same procedure was followed in Experiment II using a nonverbal line-orientation task.

The results from both experiments did not support the Hemispatial model. Instead, a RVF advantage for verbal stimuli and a LVF advantage for nonverbal stimuli were demonstrated regardless of the hemispatial location of the VHFs. These findings support the Direct Pathway Transmission model.

INTRODUCTION AND LITERATURE REVIEW

The brain, like the heart or the liver, is customarily thought of as a single structure. But unlike the heart or the liver, the brain is divided into two distinct halves, or hemispheres, which are tightly packed together inside a bony skull, and linked together by large bundles of nerve fibers serving as communication channels between the left and the right. Recognition of this duality in man's brain can be dated back as far as Hippocrates in 400 B.C. (Dimond, 1972). It was customary to regard the brain as a double structure in which there was morphological equivalence between the two hemispheres as well as an equivalence of function. That each half of the brain represented an exact mirror image of the other was supported by descriptions such as the following by Wigins (1844): "There was a patient in which one brain was entirely destroyed—gone, annihilated, and in its place a yawning chasm. Yet all his mental facilities were apparently quite perfect" (p. 291).

Yet at the same time, the early 1800s, others were first beginning to question this concept. An obscure country doctor, Marc Dax, has been cited as originating the view that the two cerebral hemispheres are not equipotential, at least as far as language functions are concerned (Dimond, 1972). In 1836, he presented this idea as his first and only scientific contribution to a medical conference. His paper received little interest and was soon forgotten. Thirty years later, however, the idea reemerged when Broca's (1865) first publication provided evidence that the left hemisphere specifically was preeminent with respect to language, and supported his conclusion by documenting that his cases of aphemia, or speech loss, resulted from damage to the left half of the brain exclusively.

Thus the notion of an asymmetrical lateralization of function, or cerebral dominance, began, and subsequent interest in associating particular cognitive functions with the left or right hemisphere has resulted in an enormous amount of research (see recent reviews by Dimond & Beaumont, 1974, and Milner, 1974). Clinical investigators have compared the deficits of patient groups with unilateral cerebral lesions or complete hemispherectomy involving either the left or right hemisphere. Speech and other related verbal abilities in right-handed people are disrupted subsequent to damage in the left hemisphere, whereas certain kinds of right-hemispheric damage results in severe perceptual, spatial, and attentional problems, as well as in problems with emotional processing and musical and singing deficits (Gordon, 1974; Heilman, Schwartz, & Watson, 1978; Kimura, 1963; Luria, 1970; Meyer & Yates, 1955; Milner, 1962; Mountcastle, 1962; Parsons, Vega, & Burns, 1969).

Another source of clinical evidence for brain asymmetry comes from the use of intracarotid amobarbital testing. This procedure, introduced by Wada and Rasmussen (1960), temporarily anesthesizes one cerebral hemisphere, thus simulating many of the acute effects of a surgical hemispherectomy (Gordon, 1974). The injected drug acts to depress most, if not all, hemispheric functions on the side injected for a 2-3 minute period. If a function is impaired by unilateral amobarbital, then the participation of that hemisphere, for the function in question, is implied. Consistent with the lesion evidence, injection of amobarbital to the left hemisphere has been found to disrupt speech (Rosadini & Rossi, 1967). Gordon (1974) found that amobarbital injected into the right hemisphere caused difficulties in melodic singing.

In 1940, a permanent surgical procedure was first applied to the human brain which would allow the left and right hemisphere to be examined independently (Van Wagenen & Herren, 1940). This procedure, called commissurotomy, involves cutting the cortical pathways that normally connect the right and left hemispheres. Although the right and left hemispheres are disconnected, each is nonetheless able to sense, perceive, experience, and respond to the world (Sperry, 1968). Because information cannot be communicated between the two hemispheres, stimuli presented to one hemisphere will be processed and responded to by that hemisphere without contribution from the opposite side of the brain. Ensuring that stimulation is confined to only one hemisphere requires special procedures. In vision, both eyes are fixed on a central point with stimuli flashing briefly to the left or right of fixation. A contralateral rule then applies: Stimuli to the left of fixation are projected to the right half of the brain; stimuli to the right of fixation are projected to the left half of the brain (Dimond, 1972). Similarly, in tactile processing, stimuli to the left hand are projected to the right half of the brain and stimuli to the right hand are projected to the left half of the brain. This general contralateral rule applies as well to the registration of auditory information although the anatomical arrangement is slightly different. Each ear sends both contralateral and ipsilateral projections from the level of the superior olivary complex upward (Berlin, 1977). The pathways connecting the ears to their opposite or contralateral hemispheres, however, are argued to be more effective (Kimura, 1967). This conclusion is based on electrophysiologic evidence from animal studies which have shown that under the stimulus conditions that cause a sound to be heard the cortical activity is greater at the contralateral cerebral hemisphere (Rosenzweig, 1954).

Subsequent to commissurotomy, a number of so-called "split brain" patients have had each of their cerebral hemispheres tested, as an isolate, with a variety of stimuli, through the various sensory modalities (Akelaitis, 1944; Franco & Sperry, 1977; Gazzaniga, 1970; LeDoux, Risse, Springer, Wilson, & Gazzaniga, 1977; Levy-Agresti & Sperry, 1968; Milner & Taylor, 1971; Myers, 1956; Myers and Sperry, 1958). The results again point to the relative importance of the left hemisphere in linguistic processing, especially for speech production, and the right hemisphere in perceptual, spatial, and musical abilities.

The clinical data reviewed thus far have provided consistent evidence that the two cerebral hemispheres are not equipotential in terms of function. A very simplistic position is that the left hemisphere is dominant for linguistic processing while the right hemisphere dominates visuo-spatial processes. This is the "traditional conservative assumption which is safe" (Moscovitch, 1979, p. 119). It is important to recognize that the term dominance for a given function, is a cautiously used descriptor. Current thinking is sensitive to the fact that both hemispheres may have the capacity to perform a task, whereas only one has the tendency to do so or is dominant for a particular ability (Dimond, 1972).

Clinical evidence concerning brain function is, however, fraught with difficulty and has been subject to a great deal of criticism. Basically, we cannot draw firm conclusions about the workings of the normal brain solely from observations of abnormally working brains. As Dimond (1972) remarks, "Fortunately, most people are neurologically normal, having two undamaged hemispheres connected by intact commissures. What do studies of brain-damaged and split-brain patients tell us about the rest of humanity?" (p. 61). Indeed, rigorous conclusions regarding normal function require the confirmation of clinical evidence in the study of normal brains. This challenge has resulted in the development of ingenious techniques to lateralize stimuli to one hemisphere or the other within an intact system.

Asymmetries in the Normal Brain

Work with normal subjects has provided much indirect evidence for differential specialization of the two sides of the brain: in vision with tachistoscopic presentations to opposing visual fields, in hearing with dichotic listening procedures, and in tactile sensation by the use of dichaptic presentations to the two hands (Milner, 1971). Each can be considered separately for clarity, but the findings are consistent across modalities, indicating some generality in the organization of brain asymmetries, or laterality, for the different sensory modalities.

Asymmetries Found in Auditory Studies

Broadbent (1954) first reported that, when competing speech messages are presented simultaneously to both ears, more messages are processed accurately by the right-ear channel than by the left-ear channel. Although primarily interested in selective attention, he had inadvertently devised a method, called dichotic listening, which was soon adopted for studying brain asymmetries.

Kimura (1961) was one of the first investigators to use the dichotic listening procedure to examine asymmetrical auditory processing in normal subjects. She noted the evidence from animal electrophysiologic studies suggesting that the contralateral projections from ear to brain are stronger or more effective than the ipsilateral pathways (Rosenzweig, 1954). She reasoned that, when two different stimuli are presented simultaneously to each ear, the difference in strength of the pathways may be exaggerated so that information sent along the ipsilateral route is suppressed or partially occluded (Kimura, 1967). (In Figure1 her schematic representation of this arrangement is presented.) Given these assumptions, it was then possible to think about the dichotic listening paradigm as similar to lateralization of stimuli into one cerebral hemisphere at a time. The initial lateralization of stimuli is easily accomplished in the visual and tactile modalities by external manipulation of the stimuli input. At best, however, lateralization is a relative phenomenon in the auditory system since anatomically it is impossible to exclude completely ipsilateral input by external manipulations. With dichotic stimulation, it seemed reasonable to assume that at least partial ipsilateral occlusion

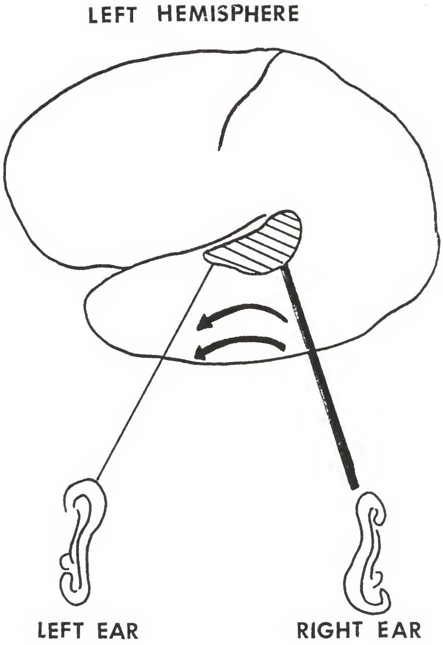

Figure 1. Schematic representation of the auditory pathways to the left hemisphere. The contralateral pathway from the right ear is "stronger" and is thought to occlude input from the left ear which occurs simultaneously (at arrows). (Source: Kimura, 1967.)

occurred, and that this procedure therefore promised the best compromise for lateralizing sound stimuli.

What is measured in dichotic listening is the advantage one ear of input has over the other for the perception or processing of various stimulus types. There can be either a right-ear advantage, symbolized REA, reflecting quicker or more accurate processing in the left hemisphere (contralateral rule), or a left-ear advantage, LEA, reflecting quicker or more accurate processing in the right hemisphere.

Much evidence exists showing that verbal material is more readily identified, recalled, and recognized when presented to the right ear. Included are digits, words, and consonants, and the effect is popularly referred to as the REA. For example, Kimura (1961) tested normal right-handed subjects using pairs of spoken digits aligned for simultaneity of onset. Subjects listened to three pairs of numbers presented to each ear in rapid succession over headphones and were asked to recall as many of the six digits as they could. They reported the digits presented to the right ear more accurately than those presented to the left ear.

A similar task using a different measure of asymmetry confirms the REA for verbal stimuli. Levy and Bowers (1974) collected manual reaction time (RT) responses to a verbal target digit which was embedded within a series of dichotically presented nontarget digits. They found that target digits presented to the right ear were responded to more rapidly than targets presented to the left ear. An examination of the response of each subject revealed that significantly more subjects displayed a REA (n=36) than a LEA (n=4).

Investigations using letters and words have also demonstrated the REA. Kimura (1967), using unisyllabic word presentations, reported similar results. There was a REA even when the order of report between the ears was controlled. Further studies have revealed that even individual components of verbal stimuli, such as consonants, are processed more efficiently when presented to the right ear (Studdert-Kennedy & Shankweiler, 1970; Zurif & Bryden, 1969). And, interestingly, backward speech is also identified more accurately when presented to the right ear (Kimura & Folb, 1968).

Left-ear advantages have been reported, although less consistently, for the processing of nonverbal stimulation. Kimura (1964) reported a LEA in the recognition of melodic excerpts. This involved dichotomous presentations of familiar or unfamiliar piano melodies which were to be subsequently picked out from a multiple-choice recognition set. A greater number of accurate identifications were made for the melodies played to the left ear than for those played to the right ear. This LEA also applied to presentations of hummed melodic patterns and for vocal nonspeech sounds such as laughing, crying, and sighing (Kimura & King, 1972). And finally, Curry (1967) reported a LEA for the recognition of nonverbal environmental sounds.

Electrophysiological measures have recently been employed in attempts to substantiate the behavioral findings. Moore (1979) measured suppression of alpha brain-wave frequencies (8-12 Hz) over the left and right hemispheres while subjects listened to Mozart's Concerto in E flat or to readings of prose material. His data revealed less alpha over the left hemisphere than over the right hemisphere during the linguistic phase. Since alpha suppression is considered to be an index of cerebral activation, he concluded that his findings supported the behavioral evidence implicating the primary involvement of the left hemisphere in linguistic processing. He did not find significant alpha suppression over the right hemisphere during the concerto. He noted, however, that many of his subjects reported thinking over the days' events, which could have involved linguistic processing and thereby could have obscured the expected right-hemisphere alpha suppression during the musical condition.

Using average evoked potentials recorded from the left- and right-temporal areas, Shucard, Cummins, Thomas, & Shucard (1981) examined response amplitudes to irrelevant tone pips during verbal and musical tasks. They found higher amplitude responses to the pips over the left hemisphere when the pips occurred during performance of a verbal task and, conversely, higher amplitude responses to the pips over the right hemisphere during the musical task. As evoked potential amplitude has been used as an index of cerebral activation or attention, it was concluded once again that the left hemisphere is implicated in the processing of verbal information, while the right hemisphere is implicated for nonverbal processing.

The evidence briefly summarized above is consistent with regard to the functional asymmetry between the two hemispheres. These findings with normal subjects using the auditory modality have confirmed the clinical data which suggested the importance of the left hemisphere in verbal/linguistic processes and the right hemisphere in processing nonverbal and musical information. As Kimura (1967) concluded, "We have, then, a clear dissociation of auditory asymmetries depending on the type of stimulus presented, and these asymmetries in turn reflect differences in function between the left and right hemispheres" (p. 177).

Asymmetries Found in Visual Studies

Unlike the auditory system, the visual system is organized in such a way that stimuli can be lateralized for a brief moment to a specific hemisphere by external means, called tachistoscopic presentation. In this procedure, the subject is required to fixate on a point directly ahead while a stimulus is briefly flashed either to the left or right of the point of fixation. This procedure capitalizes on the anatomical fact that each visual half field (VHF) projects first on the contralateral hemisphere (Springer, 1977). The optic fibers from the nasal half of each retina cross at the optic chiasm and project contralaterally, whereas the temporal half of each retina projects ipsilaterally. Since the image of an object presented off midline falls on the nasal portion of one retina and the temporal portion of the other, _initial_ lateralization of input to the striate cortex of only one hemisphere occurs. Stimuli must be presented only briefly, however, so that eye movements cannot result in input to both hemispheres. Naturally, in normal brains information can be transferred from one hemisphere to the other across the commissures; therefore, tachistoscopic presentation allows information to be lateralized only initially. What is examined is the comparison performance for stimuli projected initially to the right or initially to the left cerebral hemisphere.

Like the data collected from the auditory system, many studies using tachistoscopic presentations to the eyes have demonstrated opposite superiorities of the left and right hemispheres for verbal and nonverbal material. This can be measured in terms of accuracy or by manual RTs to target stimuli or in decision processes.

A number of early investigators (Miskin & Forgays, 1952; Orbach, 1953) reported that recognition for groups of English letters exposed tachistoscopically on either side of a central fixation point was more accurate when those letters occurred in the right visual field (first projecting to the left cerebral hemisphere). Bryden (1965) reported that single-letter stimuli were also more accurately identified when briefly exposed (20 msec.) to the right visual field than when shown in the left visual field. Kimura (1966) and, more recently, McKeever and Huling (1971) have substantiated this finding with similar alphabetical material. These findings of a RVF superiority for verbal material in vision are consistent with the REA found in the auditory modality. Both reflect superior performance of the left hemisphere in processing this type of material.

Studies of the perception of nonverbal stimuli which are expected to show opposite visual-field effects have also been undertaken. Kimura (1966) found that nonsense figures as well as groups of dots were more accurately perceived when presented in the LVF. In a subsequent study, Kimura (1969) required subjects to map onto a grid of numbered spatial positions the location of a single dot shown in either the right or left visual field. Simply detecting these dots did not result in any asymmetry between the visual half fields, but spatial localization showed the expected LVF superiority (this was significant for male subjects only).

Fontenot and Benton (1972) examined the accuracy of identification for direction of lines presented to the two visual fields. Subjects viewed a tachistoscopically presented angled line and were asked to identify the stimulus in a subsequent multiple-choice recognition task. They reported that accuracy was significantly better for lines viewed in the LVF than those viewed in the RVF.

Another nonverbal ability, facial recognition, has become a "popular" source for producing LVF/right hemisphere superiorities. This finding emerged from clinical investigations among patients with cerebral disease, which noted an association between right hemispheric damage and impaired facial recognition, called prosopagnosia (De Renzi & Spinnler, 1966; Warrington & James, 1967). Hilliard (1973) tested this relationship in normal subjects by use of a tachistoscopic method to lateralize unfamiliar photographs of faces. Subjects were to respond "same" or "different" depending on whether a briefly exposed comparison face presented centrally matched a test face tachistoscopically presented in either the left or right visual field. His data revealed that this task was performed more accurately when the test face was presented to the LVF. This effect has also been reported for nonphotographic faces, such as those produced from police Identi-Kits (Geffen, Bradshaw, & Wallace, 1971).

Like the results from dichotic listening experiments, the visual data support the notion of functional asymmetries between the two cerebral hemispheres. The left hemisphere is superior in terms of speed and accuracy for stimuli of a verbal nature, and, conversely, the right hemisphere is superior in the realm of nonverbal aspects of visual perception.

Asymmetries Found in Tactile Studies

The tactile modality is arranged much like the visual modality in that tactile information from the left hand is initially processed in the right hemisphere and tactile information from the right hand is initially processed in the left hemisphere (Benton, Levin, & Varney, 1973). Therefore, like the visual modality, the special role of the right hemisphere in processing nonverbal information should be reflected in a left-hand superiority.

Benton et al. (1973) were among the first investigators to find hemispheric asymmetries in the tactile modality. They used stainless steel rods which could be positioned in one of four directions and pressed into the palm of the right or left hand. Stimulation was one second in duration and subjects were to identify the felt direction on a visual display card representing the four possibilities. The accuracy of the identification was recorded, and the results showed significantly greater accuracy with the left hand (a right hemisphere superiority) than with the right hand. This finding was consistent with predictions from previous auditory and visual studies with nonverbal material.

In a later study, Benton, Varney, and Hamsher (1978) removed the visual component of their previous matching paradigm and required subjects to make a unimodal match between two tactile stimuli without reference to a visual display card. This removed the possibility that the cross-modal nature of the original task contributed to the left-hand/right-hemisphere superiority. They essentially replicated their findings. The same left-hand superiority in direction perception was demonstrated in this unimodal matching task as was found in the cross-modal tactile-visual matching task.

Shape recognition through the tactile modality has also been examined (Gardner, English, Flannery, Hartnett, McCormack, & Wilhelmy, 1977). Nonsense shapes cut from styrofoam were felt by either the left or right hand and were later identified by either a manual or vocal response. Both accuracy and response latency were measured. In the manual response condition, subjects more accurately recognized the shapes felt with the left hand. No significant differences were noted with response latency measures or in the vocal response mode. Gardner et al. concluded that the lack of a response-latency effect between the two hands indicated that both hemispheres are capable of processing this type of information. The accuracy differences, however, suggested that the left and right hemispheres do not perform the task equally well. This finding emphasizes the point made earlier, that dominance reflects a superiority or an enhanced tendency to process a particular type of material, even though both hemispheres may possess the capacity to do so.

A paucity of literature exists concerning the processing of linguistic material presented tactually, which may reflect a difficulty in finding significant hand differences with this type of stimuli. For example, Witelson (1974) employed both linguistic (letters) and nonlinguistic (nonsense shapes) stimuli in her investigation of tactual perception. She found the expected left-hand superiority for identifying the nonsense shapes, but failed to find a right-hand superiority for letters. She hypothesized that one possible reason for the difficulty in attaining the expected result may be that, although tactual letters are linguistic symbols, they are also spatial stimuli and, to this extent, may be dependent on right-hemispheric functioning for spatial analysis.

One published study which does report a right-hand superiority in the tactile recognition of verbal stimuli is that of Oscar-Berman, Rehbein, Porfert, and Goodglass (1978). The paradigm they used was carefully planned to maximize the probability of uncovering asymmetries. Like the dichotic listening procedure, this procedure involved the identification of two tactile stimuli presented simultaneously, one to each hand (dichaptic technique). In addition, a verbal identification was required, maximizing left-hemispheric involvement, and the report for each hand was required to follow a predetermined order so that first- and second-hand reports could be compared. There have been indications that storage of verbal material, as measured by second-hand reports, is a more sensitive measure of laterality that an immediate response. Under these conditions a significant right-hand superiority was found for letter identification, but only for the second-hand reports. The experiment of Oscar-Berman et al. also included a nonverbal line identification condition which replicated previous findings of a left-hand superiority for such material.

The tactile modality, although less thoroughly examined, has been found to possess asymmetries which parallel those documented in the visual and auditory modalities. Consistent left-hand superiority has been reported for the tactual identification of nonverbal/spatial material, which is in agreement with left-ear advantages and left-visual-field findings for stimuli presented, respectively, to the auditory and visual systems. Right-hand superiority for verbal stimuli is more difficult to demonstrate, but the one experiment reviewed here reported a significant result in the expected direction.

That these asymmetries exist is "unquestioned" (Dimond, 1972, p. 13). One simplified conceptual framework characterizes these asymmetries as reflections of the left hemisphere's dominance, or superior ability, to process verbal information. The right hemisphere is thought to be superior in nonverbal spatial abilities. Other formulations have been posited which view the asymmetries not on a verbal/nonverbal dichotomy but as differences in the processing strategies of the two, the left being superior for sequential processing and the right hemisphere being superior for analytic-holistic processing. (For an excellent discussion of this conceptualization, the reader is referred to Moscovitch, 1979). Although arguments can be made in favor of this view, to do so is beyond the scope of this dissertation. What is important here is the recognition that the two hemispheres are not equipotential, that asymmetries can be demonstrated in normal subjects which are consistent with the data gathered from clinical populations, and, finally, that these asymmetries are paralleled across sensory modalities.

Three distinct models have been proposed to account for the asymmetries found in dichotic listening, tachistoscopic viewing, and tactile perception. Historically, the earliest explanation was formulated by Kimura following her series of laterality studies in the 1960s (Kimura, 1961, 1963, 1966, 1967, 1969). Later, as evidence surfaced which contradicted her model, an entirely different model was proposed by Kinsbourne (1970b, 1973). His model is currently being tested, and a new model which is similar to Kinsbourne's has been proposed by Bowers and Heilman (1980). Each of these models will be reviewed below.

Kimura's Direct Pathway Transmission Model

Recall from the previous sections Kimura's extensive series of laterality studies (1961, 1963, 1966, 1967) which consistently revealed a REA/left hemisphere superiority for dichotically presented verbal material, and an opposing LEA/right hemisphere superiority for nonverbal material. In conceptualizing her findings, Kimura (1961, 1966) developed an explanatory model which has become known as the Direct Pathway Transmission model of laterality.

In this model, two main components are essential. First, Kimura relates the observed asymmetries in normal human perception to an asymmetrical representation of function in the cerebral hemispheres. For some time prior to her hypothesis, clinical and experimental methods documented that language was predominantly represented in the left hemisphere, at least in normal right handers (Zangwill, 1960). Kimura (1967) stated her belief that the perceptual asymmetries she observed in normals reflected this unequal distribution of language in the brain:

"The evidence is overwhelming that the asymmetrical functioning of the two halves of the brain for speech is reflected in [the] unequal perception of words presented dichotically to left and right ears" (1967, p. 167).

The second component of her model is anatomical and deals with why a REA is found for verbal material which is functionally processed by the left hemisphere and, conversely, why a LEA is found for nonverbal or functionally right-hemispheric materials. Kimura (1961) stated that in dichotic listening the contralateral ear-to-cortex pathways were the strongest or most effective. Ipsilateral projections were thought to be suppressed or partially occluded during dichotic presentation. She drew these opinions from the physiological findings of Rosenzweig (1954). It followed from this anatomical arrangement that, during dichotic listening, a right-ear verbal stimulus would directly enter the left hemisphere through the strong contralateral pathway. For a left-ear stimulus to arrive at the left hemisphere for processing, it would first pass directly along the stronger contralateral projection into the right hemisphere and then have to be transfered to the left hemisphere via the corpus collosum commissures (Sparks & Geshwind, 1968). (Figure 2a illustrates these pathways.) Kimura (1966) proposed that input transmitted along the shorter, more direct pathway in some way better maintains its integrity. Right-ear stimuli gain access to the left hemisphere through the shorter contralateral route, and, because they do not have to cross the corpus collosum as do their left-ear counterparts, a small right-ear advantage emerges for verbal material (Dimond, 1972). By reversing the left and rights, Kimura's model

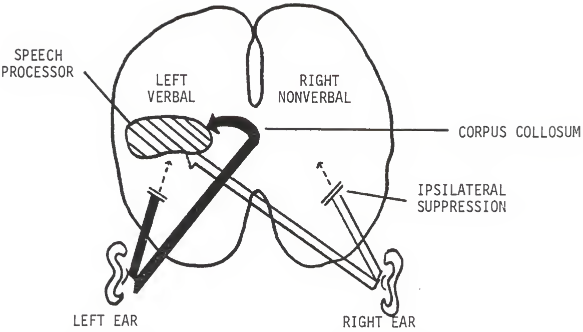

Figure 2a. Schemata of Kimura's (1961) Direct Pathway Transmission model. The right ear advantage is said to be due to its having the shortest route to the verbal processor (white arrow). Left ear messages (black arrow) must go through the corpus collosum.

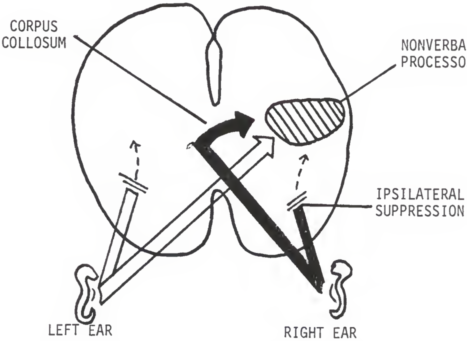

Figure 2b. Schemata same as 2a for nonverbal material, showing LEA.

can also account for the LEA found for nonverbal material (see Figure 2b).

Some support for this anatomical model came from work with split-brain patients. The commissurotomy procedure cuts the corpus collosum but does not affect the contralateral or ipsilateral sensory projections which are subcortical (Dimond, 1972). If, as Kimura suggested, the ipsilateral pathways are suppressed or partially occluded in dichotic listening, then split-brain patients should only be able to report words which have entered their right ear and been projected contralaterally to their speech hemisphere. Left-ear words cannot cross the corpus collosum after being projected contralaterally into the right nonverbal hemisphere. Their only access is through the ipsilateral projection, and, if Kimura is correct about the ipsilateral suppression, then report from the left ear should be very poor. Milner, Taylor, and Sperry (1968) found these predictions to hold true. Split-brain patients in a dichotic listening paradigm reported the right-ear verbal items accurately, but left-ear report was at a chance level. In fact, patients sometimes had to be coaxed into guessing, believing that they had heard only one word. When words were presented monaurally (to one ear at a time), these patients could report words presented to either ear, which was predicted from Kimura's model since ipsilateral suppression is expected only with dichotic presentations.

Kimura's model has been extended to account for asymmetries found in the visual modality (Rissolatti, Umilta, & Berlucchi, 1971). The foundation for the model remains the same. Firstly, the predominance of the left hemisphere in the analysis of verbal material and the right hemisphere in the analysis of nonverbal or spatial material is accepted. Secondly, it is suspected that the anatomical arrangement of the retinocerebral connections plays a crucial role. But how these anatomical and functional properties precisely determine the observed asymmetries is not resolved (Berlucchi, Brizzolara, Marzi, Rizzolatti, & Umilta, 1974).

One hypothesis (Rizzolatti et al., 1971) is a direct parallel to Kimura's (1966) explanation of the auditory system. It states that the visual field connected to the specialized hemisphere benefits from a more efficient transmission of information by a relatively shorter neural pathway leading to the analyzing center. Information presented in the subordinate visual field would, on the contrary, have to travel along a less direct pathway, crossing through the commissures, before being analyzed. Like the auditory explanation given by Kimura (1966), it is implied that the more direct contralateral pathway produced the RVF advantage for verbal material and, likewise, for the LVF and nonverbal material.

From these descriptions it is obvious why Kimura's model for laterality has been called anatomical (Kinsbourne, 1970a), connectionistic (Donnefeld, Rosen, Mackavey, & Curcio, 1976), and structural. Studdert-Kennedy (1975) has described it as a "wiring account of ear advantages in terms of ear-to-hemisphere connections" (p. 124).

This strict view has met with some conceptual arguments. Kinsbourne (1970a) claimed that the less direct pathway would require an extra synapse to cross the corpus collosum, which would add "some four milliseconds to the total conduction time" (p. 198). Yet

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asymmetries in response latency, manual RTs, are much greater, with some reports of differences up to 132 msec. (Levy & Bowers, 1974). Neutral stimuli such as simple lights (Kerr, Mingay, & Elithorn, 1963) and sounds (Simon, 1967) show RT asymmetries (right-sided superiority) even though this is not predicted by Kimura's model. Finally, Kinsbourne (1970a) noted the difficulty which has been encountered with the nonverbal and musical material. He concluded that asymmetries based on "structural invariants should be more robust" (p. 198).

One of the main components of Kimura's model is that dichotic presentation results in asymmetrical ear advantages due to ipsilateral suppression or partial occlusion. This assumption has been tested by studies which have found laterality effects without the dichotic presentations of stimuli to one ear and thereby one neuroanatomic pathway. Morais and Bertleson (1973) replaced the earphones traditionally used for dichotic presentation with two externally located loudspeakers, one to the right and one to the left. Despite the fact that both neural pathways received the same information, the REA was still found for the verbal material. Monaural presentation of tonal sequences and speech has also been reported to produce LEA and REA, respectively (Doehring, 1972; Fry, 1974). Since Kimura's model states that dichotic listening with subsequent ipsilateral suppression is necessary to produce asymmetries, these findings cannot be accounted for by her formulations.

Some interesting results have been reported even when dichotic listening is employed. Goldstein and Lackner (1974) had subjects wear Risley prisms which visually displaced their environment while listening to a standard dichotic listening tape of consonant-vowel syllables.

As expected, they found a right-ear advantage for the verbal material in the no-displacement condition. When subjects' vision was displaced to the right, the REA increased in magnitude and, conversely, was decreased in magnitude with left visual displacement. Goldstein and Lackner stated that attentional and spatial mechanisms are important factors to be examined.

Another challenge of Kimura's model has come from recent studies which in no way altered the anatomical pathways but which reported manipulating manual RT asymmetries. These studies also suggest the importance of spatial variables and seriously question Kimura's Anatomical model. For example, Simon, Hinrich, and Craft (1970) reported a consistent finding that subjects respond more rapidly to lateralized neutral stimuli when the side of the stimulation and the side of response execution correspond. In a typical experimental paradigm, subjects respond to stimuli which are presented to either the left or the right ear or to the left or right visual half field by depressing keys on the left and right side of the body. This is done with the left and right hands crossed and uncrossed. Regardless of whether the hands are crossed or uncrossed, faster RTs are made by the hand positioned on the same side of space as the stimulus presentation. This phenomenon is called stimulus-response (S-R) compatibility and has been demonstrated with choice RTs in both the auditory and visual modality (Anzola, Bertoloni, Butcher, & Rizzolatti, 1977; Bertera, Callan, Parsons, & Pishkin, 1975; Callan, Klisz, & Parsons, 1974). Such findings dispute the integrity of a pathway transmission model, since moving the hands from one side of space to another can alter RTs to stimuli, without altering the anatomical connections between the sensory inputs and the cerebral hemispheres (Bowers, Heilman & Van Den Abell, 1981). Pieters (1979) concluded that direct pathway models based solely on transmission differences across the corpus collosum are inadequate explanations of asymmetrical functioning. He presented the idea that S-R compatibility and hemisphere specialization are separate factors, both affecting the response process, and that both are worthy of investigation.

In the seventies, Kinsbourne developed and introduced an Attentional model to explain laterality effects which would avoid many of the criticisms attached to Kimura's Anatomical model. In the subsequent examination of Kinsbourne's model, facts emerged which further jeopardized the viability of Kimura's model. (These findings will be discussed in the following section.) However, Kimura's model is still popular and frequently appears in the discussion section of research papers to explain partial findings which are consistent with it.

Kinsbourne's Attentional Model

Man is constantly bombarded by sensory events to which he must selectively respond, depending upon their relevancy. Attention is the mechanism he uses to accomplish this. According to Kinsbourne's model (1970a, 1974a), each cerebral hemisphere in man drives attention toward contralateral space. Microelectrode studies in animals have demonstrated the existence of such an arrangement. Lynch, Mountcastle, Talbot, and Yin (1977) found that in monkeys somatic, visual, and oculomotor signals all converge on cells in the inferior parietal lobule, area number 7. They identified a population of attentional cells, 57% of the 907 neurons they studied, which fired selectively for interesting or relevant stimuli. Significantly, the majority of these cells fired only when a visual target was located within contralateral space.

Extending this type of contralateral attentional mechanism to the human brain has important implications in explaining perceptual asymmetries. Kinsbourne (1970a) concluded that the right hemisphere subserves attention to left space and the left hemisphere subserves attention to right space. Furthermore, the balance between the hemispheres at any one moment determines the direction, or side of space, to which the organism is attending. The crucial elements to his model are (1) the type of ongoing activity or expectancy for a particular type of activity serves to activate the corresponding hemisphere in a diffuse fashion, and (2) this diffuse activation makes the organism more sensitive to stimuli occurring in contralateral space (Bryden, 1973). The following example illustrates these principles for left- and right-hemispheric processes. Kinsbourne would argue that verbal thought activates the left hemisphere in agreement with previous findings revealing this functional superiority. Activation of the left hemisphere would in turn make the organism more sensitive to stimuli occurring in the right side of space. Conversely, nonverbal activity such as musical thought would activate the right hemisphere, and this would result in heightened sensitivity to the left half of space. In sum, Kinsbourne's model proposes that ongoing activity or expectancies bias attention toward the contralateral spatial field. Once a hemisphere is activated and has induced attention to its contralateral field, the sensitivity for the perception of stimuli occurring in that field is increased.

His model was adequate to account for the existing dissociations between verbal and nonverbal input found in dichotic listening, tachistoscopic, and tactile studies. For instance, where right-sided advantanges were found, an attentional explanation could be invoked. The expectation of verbal material or the repeated presentation of letters, words, prose, etc., activated the left/language hemisphere. This in turn biased attention to the contralateral right side of space, which enhanced right-sided sensitivity. Therefore, RTs, recall, accuracy, and other measures of performance were better for stimuli occurring in the right side of space.

In addition, Kinsbourne's model handles findings of lateral asymmetries in monaural presentation and where dichotic presentation occurs in a free field over loudspeakers. Recall the studies by Doehring (1972) and Fry (1974) using monaural stimulation and Bertleson (1973) using loudspeakers. All three studies found expected asymmetries which were consistent with the functional specialization of the hemispheres. Kimura's Direct Pathway Transmission model does not account for these findings, but contralateral attentional biases as described by Kinsbourne may be operating. These do not depend on structured anatomy and therefore can be used to explain such results.

Kinsbourne's model can be tested in its own right with experiments which he and others have undertaken (Berlucchi et al., 1974; Gur, Gur, & Harris, 1975; Ehrlichman & Weinberger, 1979; Ehrlichman, Weiner, & Baker, 1974; Kinsbourne, 1970a, 1973, 1977; Morais &

Landercy, 1977). These experiments involve priming one hemisphere with material it processes best and examining the effects this has on performance in left and right space in a variety of tasks. By priming a particular hemisphere, one should be able to induce cognitive or attentional sets which are either verbal or nonverbal (Kinsbourne, 1973). Cognitive set refers to the set of expectancies induced by the task parameters or by pretask activities or instructions. A verbal set would be expected to enhance sensitivity on the right side of space since it acts to prime the left hemisphere (Bowers & Heilman, 1980).

In one of his first empirical efforts to support his model, Kinsbourne (1970a) required subjects to engage in a spatial task, judging the location of gaps in tachistoscopically presented squares. This was performed in a standard condition and in a condition of subvocal rehearsal of six words, and was intended to prime the left hemisphere. He found that gap detection was symmetrical without the verbal activity, but inducing subvocal rehearsal resulted in a RVF/left hemisphere advantage. He concluded that verbal activity activated the left hemisphere, biasing attention to the right side of space, thereby causing a RVF advantage where there otherwise was not one. Kimura's Direct Pathyway Transmission model cannot account for this phenomenon.

In an effort to extend these initial findings, Goodglass and his co-workers (Goodglass, Shai, Rosen, & Berman, 1976) reported an experiment in which three types of stimuli—nonsense figures, three-letter words, and dots—were tachistoscopically presented for identification under no set, verbal shadowing, and musical shadowing. They found a significant improvement in performance in the LVF when music was being shadowed. They had partially supported Kinsbourne's model and concluded that music had activated or primed the right hemisphere which in turn enhanced performance in contralateral/left space. They did not, however, find the opposite effect with the verbal shadowing.

Klein, Moscovitch, & Vigna (1976) used two different priming materials, words and faces, to prime the left and right hemisphere, respectively. Subjects were divided into two groups: One received the words first for left hemispheric priming, followed by a facial recognition task; the other received the faces first as priming for the right hemisphere, followed by the word task. The results again only partially supported Kinsbourne's model. Priming the left hemisphere with the verbal task first diminished the right hemisphere's superiority for the subsequent facial task. The LVF and RVF performed equally in the facial task. Priming the right hemisphere with faces, however, did not diminish the left-hemispheric superiority for the words which followed. The RVF was still better than the LVF for the word task. Klein et al. concluded that "the evidence presented in this study make it difficult to argue for any single mechanism" (p. 59). The behavior of the group receiving words to prime the left hemisphere was consistent with the Attentional model, whereas that of the facial priming group was not.

Another paradigm has been designed to test the Attentional model and has generally produced negative results (Berlucchi et al., 1974; Dee & Hannay, 1973; Donnenfeld et al., 1976; Kallman, 1978). This paradigm presents verbal and nonverbal material, dichotically and tachistoscopically, in a random, mixed fashion. From Kinbourne's model it is predicted that without prior knowledge of the nature of the impending stimulus, there can be no preparatory activation or attentional bias of the hemisphere specialized for a particular stimulus class. Under these conditions, Kinsbourne's model predicts that no lateral asymmetries should be found. Berlucchi et al. (1974) tested this hypothesis using letters and faces as stimuli. Despite the fact that their presentation was randomly intermixed, they found the predictable laterality effects. Letters still produced a RVF superiority and faces produced a LVF superiority. Similarly, Dee and Hannay (1973) found a LVF superiority for form recognition and a RVF superiority for verbal trigram recognition. In the auditory modality, Kallman (1978) found a REA for speech sounds and a LEA for musical sounds when the dichotic presentation was randomized. These three studies provide little support for Kinsbourne's model in either dichotic or tachistoscopic tasks which were specifically designed to test his assumptions. Therefore, even though this model can account for existing laterality effects, and can account for some findings which the Direct Pathway Transmission model cannot, it too has problems.

Bowers and Heilman: Activation Model

Bowers and Heilman (1980) raise a critical theoretical issue regarding Kinsbourne's (1970a, 1973) Attentional model. These authors noted that three components of attention can be delineated, and each may be mediated by entirely different neural systems (Pribram & McGuiness, 1975): Arousal has been described as a phasic physiological response to stimulation which produces increased stimulus receptivity (see Sokolov, 1963); attention refers to the selective component of stimulus processing; and, finally, activation is the readiness to respond or intentional component which refers to an organism's preparation for action (Pribram & McGuiness, 1975).

According to his own descriptions, Kinsbourne's (1970a) Attention model addresses perceptual asymmetries which are brought about by attentional sets, which asymmetrically activate the left and right hemispheres. Bowers and Heilman (1980) pointed out that Kinsbourne's model does not actually deal with activation in its true intentional meaning. Instead, Kinsbourne's model deals with differential perceptual changes or receptivity changes which are more appropriately related to arousal (Sokolov, 1963). His proposal that stimuli contralateral to an activated hemisphere are better perceived is technically corrected to read, stimuli contralateral to an aroused hemisphere are better perceived. This position emphasizes the more afferent components of attention (Bowers & Heilman, 1980).

The Activation model proposed by Bowers and Heilman (1980), on the other hand, emphasizes the true intentional component of activation. They posited that hemispheric asymmetries emerge when stimuli differentially prepare the hemispheres for action rather than when perceptual receptivity changes. This model has not yet been extensively tested; some support, however, comes from a recent warning stimulus-reaction time paradigm (Bowers & Heilman, 1976). In this paradigm subjects respond to a neutral RT tone which could be preceded by either a verbal or nonverbal warning stimulus (WS). Reaction times to the tones were obtained for the right and left hands. It was found that verbal WS reduced RTs of the right hand (left hemisphere) more than those of the left hand. Importantly, this RT asymmetry occurred only when the verbal WS conveyed relevant information regarding the type of behavioral response which should be made, not in a simple RT

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condition. This indicates that response-linked decisional processes are critical for these RT asymmetries. It suggests that "verbal stimuli (WS) asymmetrically activate and prepare the left hemisphere for action" (Bowers & Heilman, 1980, p. 315). This supports the notion of an intention or readiness-to-respond distinction. However, as is found throughout the literature, producing the opposite right-hemispheric phenomenon is more difficult. In this experiment, the nonverbal WS did not produce RT asymmetries.

Theoretically, the distinction between Kinsbourne's (1970a) model and the Activation model of Bowers & Heilman (1980) becomes important if one recognizes that the components of attention described by Pribram and McGuiness (1975) are dissociable. It is then possible to hypothesize that asymmetries could "arise at any or all levels of the components . . . and may possibly have different time relationships" (Bowers & Heilman, 1980, p. 315).

Recapitulation

The preceding pages have given an overview of the laterality literature which has been published for the past twenty years. A general distinction was made that the two hemispheres were functionally asymmetrical, the left hemisphere possessing superior ability to process verbal information and the right hemisphere possessing superior ability for nonverbal materials. This dichotomy has been consistently manifested in clinical as well as normal populations, and holds true across the visual, auditory, and tactile modalities.

Three theoretical models were discussed which have been proposed to account for the observed asymmetries. The earliest model, Kimura's (1961) Direct Pathway Transmission model, suggested that asymmetries resulted from the combination of (1) the functional speciality of each hemisphere, and (2) direct anatomical pathways from the contralateral sensory receptor to the hemisphere specialized for processing a particular stimuli class. This model could not account for monaural or free-field presentations nor could it explain priming studies which can manipulate asymmetries although the anatomical pathways are left undisturbed.

Kinsbourne's (1970a) Attentional model could explain more of the existent laterality effects, but subsequent experiments designed to specifically test his assumptions met with equivocal support at best. There was some support in that priming the hemisphere with appropriate material altered the receptivity for stimuli in space contralateral to that hemisphere. Kinsbourne proposed that this reflected an attentional bias for contralateral space which occurred when the hemisphere was differentially activated during priming.

Bowers and Heilman (1980) proposed the Activation model and clarified that the term activation implied that the hemisphere could be differentially prepared to respond. This is distinguished from Kinsbourne's meaning of the term activation, which referred to differential perception or receptivity for stimuli. Evidence from WS-RT paradigms has given some support for this notion.

In conclusion, none of these models adequately account for the numerous observations of lateral asymmetry. What is implied is that further investigation is warranted. The asymmetries are there, and explanations will continue to be attempted.

A Neglected Variable: Hemispace

There is a potentially important variable which has been neglected in the laterality literature, that of hemispace. The hemispatial body field is based on an egocentric coordinate system where the median plane of the body acts as the axis for dividing external space into right and left quadrants (Gooddy & Reinhold, 1952). The external space which falls to the right of the body midline is right hemispace, and the external space which falls to the left of the body midline is left hemispace. Therefore, each hemispace can be viewed as a "perceptual field for attending to stimuli as well as a behavioral field for responding to stimuli" (Bowers & Heilman, 1980, p. 310).

The concept of hemispace has important implications for models of hemispheric laterality. One of the major theories is Kimura's Direct Pathway Transmission model, which is based on anatomical connections between the sensory input channel and the targeted hemisphere which is specialized for a particular stimulus class. This theory has enjoyed the support of numerous studies which found that verbal stimuli are better processed when presented to the right channel, whereas nonverbal stimuli are better processed when presented to the left channel. These "supporting experiments," however, have not teased out the effect of hemispace by systematically varying it within the stimuli presentations. In other words, there has been an exact one-to-one correspondence between the side of hemispace in which a stimulus occurs and the sensory channel, be it the eye, ear, or hand, which receives the stimulus.

In the traditional laterality experiment, subjects are oriented to some central point and the right side of space corresponds to the RVF, the right ear, and the right hand (see Figure 3).

Because hemispace and sensory input channel have been consistently confounded, it is not possible to determine the critical factor in laterality effects. These effects could be equally the result of

1. The anatomical relationship between the "target" hemisphere and the contralateral sensory input channel,
2. The relationship between the target hemisphere and some hemispatial mechanism involved in the mediation of perception and/or activities in the contralateral hemispatial field.

Therefore, theoretically, there is a possible brain-behavior phenomenon that has been overlooked throughout the previous research. Correcting this problem required a procedural change in the typical laterality experiment, and this dissertation proposes such an alteration in a verbal and nonverbal tachistoscopic paradigm.

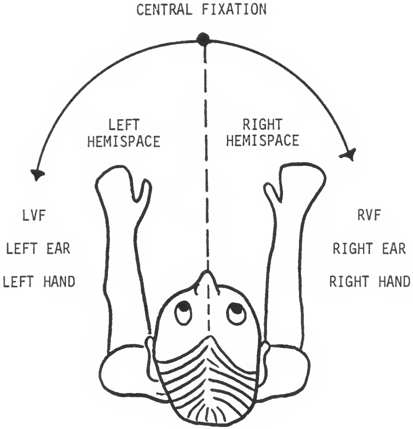

Figure 3. Schematic showing the exact one-to-one correspondence between VHF, handedness, and ear, in the typical laterality study.

PROPOSAL

Of critical relevance to this dissertation is the fact that hemispatial body field is not equivalent to VHF. Visual half field is defined according to fixed anatomical relationships; it refers to points in space which fall on the temporal or nasal hemiretinae of the eye. As the eyes move, VHF moves too, is fixed on the retina, and moves with the retina. Hemispace, on the other hand, is defined by the body and therefore moves with the body.

In the visual tachistoscopic studies of laterality done to date, these two variables have never been dissociated, even though to do so is quite simple. It requires only a simple change in the typical procedure which requires the subjects to fixate on a central point as they sit staring straight ahead. In this standard situation there is a one-to-one correspondence between RVF and right hemispace, and LVF and left hemispace (see Figure 4a). By moving the fixation point across the body midline and into, for example, right hemispace, however, one could dissociate the VHFs from their corresponding hemispatial fields. Both the LVF and RVF will follow the retina into right hemispace where the fixation point is now located (see Figure 4b). Since the body has remained stationary, however, the left and right hemispace has not correspondingly changed. This kind of direct investigation is proposed.

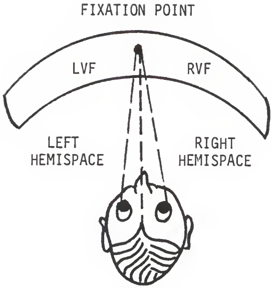

Figure 4a. Typical tachistoscopic presentation.

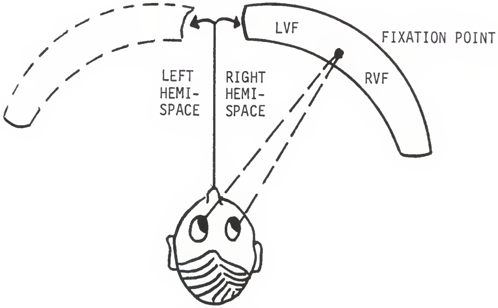

Figure 4b. Proposed tachistoscopic presentation disentangling VHF and hemispace.

Even though direct approaches are lacking (for exceptions see Bowers & Heilman, 1980; Bowers, Heilman, & Van Den Abell, 1981), there are indirect experimental results which indicate that the variable of hemispace may make an important contribution to the understanding of observed hemispheric asymmetries. In the auditory modality, Goldstein and Lackner (1974) manipulated laterality effects by visually displacing the subject's environment to the left or right. Recall that their subjects wore Risley prisms while listening to a dichotic tape of syllables. When the prisms displaced the external environment to the right, the REA for the syllables increased in magnitude. Conversely, displacing the visual environment to the left decreased the REA, revealing that external spatial coordinates, the appearance of where the sound came from, had an important impact on the resulting lateral asymmetries.

Morais and Bertleson (1973, 1975) have been interested in the influence of spatial position on laterality and have tried to dissociate this variable from ear of entry. They have also used the auditory modality and have found support for the importance of the spatial variable. In their first study they presented dichotic verbal messages over free-field loudspeakers positioned in left or right space (Morais & Bertleson, 1973). Even though information from each loudspeaker entered each ear, there was a superior reproduction of messages from the right-sided speaker. This result was consistent with the spatial hypothesis but did not invalidate the ear-of-entry explanation since intensity differences were still produced by the loudspeakers at opposite sides of the room. To rule out the possibility that intensity at ear of entry determined the right-sided advantage, Morais and Bertleson (1975) in a later study created the apparent localization of speech messages to the left and right side of space by use of stereophonic techniques, but while holding intensity between the two messages constant. They reported an advantage for messages which appeared to come from the right side. These findings, like those in the use of the visual prism, emphasized that apparent spatial separation and position can, by themselves, produce laterality effects.

The only direct investigations of hemispace as a variable contributing to laterality effects were recently published by Bowers and Heilman (1980) and Bowers et al. (1981). Bowers and Heilman used a tactile-line bisection task, which due to its tactuo-spatial demands was expected to be more accurately performed by the right hemisphere/left-hand combination. Recall that previous studies in the tactile modality have found a right hemisphere/left-hand advantage for nonverbal stimuli (Benton et al., 1973; Benton et al., 1978; Gardner et al., 1977). Importantly, each subject performed the line bisection in three hemispatial positions: at midline, in left hemispace, and in right hemispace, with both the left and right hands. Three hypotheses were made. Firstly, it was reasoned that if the anatomical connections between the sensory channel, in this case the left hand, and the target, or right hemisphere, were crucial, then the left hand would be more accurate at finding the midpoint regardless of the hemispatial location in which the task was performed. On the other hand, if hemispace is an important variable, then line bisection should have been performed most accurately in left hemispace regardless of which hand was used to feel the stimulus. Finally, both hemisphere-input channel and hemisphere-hemispace relationships could affect laterality findings. In this case, an interaction is expected such that the optimal hand (left) should perform best in optimal space (left). The results confirmed the third hypothesis. There was a significant interaction, with the best performance obtained by the left hand in left hemispace. Bowers and Heilman (1980) concluded that

> at least for the tactile modality, laterality effects stem from at least two factors; (a) some hemispheric mechanism involved in the perception and/or execution of activities in the contralateral hemispatial fields, and (2) the anatomical connection between each hemisphere and the contralateral sensory-motor channels. (p. 317)

The second direct study of hemispace (Bowers et al., 1981) was designed to determine if there was a VHF-hemispatial compatability. Recall that previous S-R compatibility studies demonstrated a relationship between the hemispatial location of the hand and VHF (Anzola et al., 1977; Bertera et al., 1975; Callan et al., 1974; Simon et al., 1970). That is, RTs to neutral stimuli were quickest when the hand responding and the VHF of the stimulus corresponded. It was previously noted that Kimura's Direct Pathway Transmission model could not explain this phenomenon. The concept of hemispace can, however, be employed. It suggests that each cerebral hemisphere is responsible for the perception and/or mediation of activities in contralateral hemispace. This implies that spatial, not anatomical, considerations are crucial. If this is true, then one may predict finding a VHF-hemispatial compatability effect. That is, RTs to neutral stimuli would be more rapid when the VHF they are projected to is totally within its corresponding hemispatial field. Bowers et al. (1981) stated that "evidence for such a hemispace-VHF compatability effect would appear critical for the hypothesis that a functional relationship exists between each hemisphere and the contralateral space" (p. 757).

To search for this compatability effect, they measured RTs to neutral stimuli (lights) presented to the RVF and LVF. The visual fixation points were varied so that the half fields fell totally within left hemispace and within right hemispace. Subjects were instructed to respond to the onset of either a top light or a bottom light in the display, designated the "go" stimulus. They ignored the onset of the opposite light, designated the "no-go" stimulus. The results confirmed a VHF-hemispatial compatability, such that RTs to LVF stimuli were faster when the LVF fell within left hemispace and vice versa for the right side. This supports the notion that hemispace is an important factor in determining laterality effects.

STATEMENT OF THE PROBLEM

The purpose of the present study is to extend the findings which point to the significant role of hemispheric-hemispatial relationships. As noted previously, VHF studies with verbal and nonverbal material have not varied the hemispatial location of the fixation point, with respect to the subject's body, in such a way as to disengage VHF from hemispatial field. At present, lateral asymmetries found in typical VHF paradigms can be attributed to two hypotheses. One, an input-channel-target hemisphere hypothesis, suggests that visual field superiorities for verbal and nonverbal materials are due to direct anatomical pathways from the contralateral visual fields to their corresponding targeted hemispheres. Specifically, RVF superiorities for verbal materials are said to reflect a direct anatomical pathway from the RVF, contralaterally to the left hemisphere, which is targeted to process linguistic information. Likewise, LVF superiorities for nonverbal materials are said to reflect a direct anatomical pathway from the LVF, contralaterally to the right hemisphere targeted to process nonlinguistic information. This argument is based on Kimura's Direct Pathway Transmission model. A second hypothesis claims that a hemispatial-target hemisphere relationship exists whereby some hemispheric mechanism in each hemisphere controls the perception and/or activity in the contralateral hemispace. This position implies that spatial, _not_ anatomical, considerations are crucial.

This study consisted of two separate experiments, each involving a RT go-no-go paradigm using tachistoscopically presented stimuli. Each experiment varied the location of the subject's seating such that both right and left visual fields fell into right and left hemispace, separately, as well as at midline. These manipulations were designed to experimentally disentangle the two hypotheses concerning the basis of laterality effects in the visual modality.

In Experiment I, verbal stimuli consisting of four-letter nouns and verbs were presented to a group of subjects. This verbal task was intended to be more strongly mediated by the left hemisphere. It was expected that there would be a RVF superiority, faster RTs, to words presented in the midline spatial condition as compared to those occurring in the LVF presented in the midline spatial condition. This would merely replicate previous findings because, in the midline spatial condition, left and right hemispace and left and right visual fields correspond (Figure 3).

Reaction times from the other spatial conditions, however, permit a clarification between the two hypotheses, that of direct pathway transmission, or hemispatial mechanism. If the anatomical connections between the input channel and the target hemisphere were critical for laterality effects, then the stimuli projected to the RVF would be expected to result in faster RTs regardless of the hemispatial position the task was performed in. On the other hand, if hemispatial-hemispheric relationships were critical, then the verbal stimuli would be responded to quickest when they fell into right hemispace regardless of which VHF they were projected to.

The same rationale can be applied to the second experiment where a different group of subjects received nonverbal, line stimuli. This nonverbal task was designed to be more strongly mediated by the right hemisphere. It was expected that there would be a LVF advantage, faster RTs, to lines presented in left hemispace in the midline spatial condition. This finding would again merely replicate previous findings since it represents the condition where hemispace and VHF have a one-to-one correspondence.

But, as stated above, RTs from the other spatial conditions were intended to clarify between the direct pathway transmission hypothesis and the hemispatial hypothesis. If the anatomical connections between the input channel and the target hemisphere were critical for laterality effects, then the lines projected to the LVF would result in faster RTs regardless of the hemispatial position the task was performed in. If, however, hemispatial-hemispheric relationships were critical, then the nonverbal stimuli would be responded to quickest when they fell into left hemispace regardless of which VHF they were projected to.

It was thought possible that both factors may contribute to observed laterality effects. If this was the case, then a significant two-way interaction effect between VHF and hemispatial position would be expected. For the case of verbal material, it would be predicted that the fastest RTs would come from responses to stimuli projected to the RVF when it was within right hemispace. For nonverbal material, the opposite would be expected; that is, the fastest RTs would come from responses to stimuli projected to the LVF when it was within left hemispace.

It was important to investigate these two hypotheses using both a verbal and a nonverbal experimental paradigm. In neuropsychology the strongest support for a mechanism such as the proposed hemispatial-hemispheric relationship would be a double dissociation, that is, demonstrating the expected effects in opposing directions for verbal versus nonverbal conditions.

METHOD

Subjects

Thirty-six right-handed male college students who were volunteers from the introductory psychology course at the University of Florida served as subjects for the study. Because recent literature on sex differences and lateral asymmetries favor the male subject as showing the strongest cerebral dominance effects (McGlone, 1980), only male subjects were solicited for participation. Their ages ranged from 17 to 27 years; the mean age was 19.3 years. Each subject was screened on a handedness inventory compiled by Briggs and Nebes (1975), consisting of 12 items on which the strength of hand preference was scored on a 5-point scale. Each item received a +2 for "always right hand," a +1 for "usually right hand," and a 0 score for "no preference." Left-handed preferences were scored in a similar manner using negative values (see Appendix A). An overall score was obtained and, in line with current literature, a criteria of +9 or greater was used for inclusion in the experiments. In this sample of subjects the range of scores was from +11 to +24 with a mean score of +18.3. Of the 36 subjects 18 participated in the verbal experiment, Experiment I, and 18 participated in the nonverbal experiment, Experiment II. Each subject participated in six 45-minute experimental sessions.

Stimuli

Preexperimental Stimuli

Prior to each experimental session using verbal or nonverbal stimuli, each subject performed a go-no-go RT task involving simple lights. The stimuli for this procedure consisted of a bright- and dim-light-emitting diode arranged vertically, 10 cm. apart, on a display board. For each subject, the bright diode was designated as the go stimuli for half of the six sessions and the dim diode was the go stimuli for the remaining sessions.

Experiment I: Verbal Stimuli

The verbal stimuli consisted of slides of different four-letter words set in upper-case bold print that appeared white on a black background. Each word was arranged vertically on the slide to reduce the possibility of ideographic (i.e., right hemispheric) reading. The stimuli pool consisted of 48 different words of which 24 were active verbs and 24 were concrete nouns. This large set was broken down into six subsets each consisting of 8 nouns and 8 verbs. All subjects received each of these subsets over the six experimental sessions. In half of the sessions the verbs were designated as the go stimuli, and in the other half the nouns were designated as the go stimuli. In each set of words, the individual letters making up the words had minimal overlap to ensure a linguistic rather than a spatial strategy for processing. (The six subsets used are shown in Appendix B.)

Experiment II: Nonverbal Stimuli

The nonverbal stimuli consisted of slides of straight lines at different angles from horizontal which appeared white on a black background. The stimuli pool consisted of eight different lines, 18° graduations from horizontal excluding vertical (90°) and horizontal (180°) representations. The lines were 18°, 36°, 54°, 72°, 108°, 126°, 144°, and 162° as used by Fontenot and Benton (1972). Six subsets of different lines, four in each subset, were drawn from the larger pool such that each set had a different combination of lines. These subsets contained two acute angles (less than 90°) and two obtuse angles (greater than 90°). (The lines used and the subsets formed appear in Appendix C). Two lines, one acute and one obtuse, were designated as go stimuli and the remaining lines were designated as no-go stimuli.

Apparatus

Verbal and nonverbal slides were projected for 50 msec. through a Polytechnic tachistoscope situated 63 cm. behind a 35 cm. x 42 cm. projection screen. In the center of the projection screen was a small central fixation point. The stimuli presentation took place in a darkened room. In order to have the word and line stimuli appear to the left and right of the central fixation point (into left and right VHFs), they were arranged off the center of the slide, near the left and right borders. When projected, the stimulus information fell 20° to the left and right of the fixation point, providing lateralized presentations into the LVF and RVF, respectively.

The subject's seating was portable and was moved to provide the three hemispatial conditions: midline, or central; right; and left. In the central condition the subject's desk and chair were directly in

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front of the projection screen with the subject's head resting 70 cm. from the screen. In the right hemispace condition,the subject's desk and chair were moved 42 cm. to the left. By this manipulation the screen became entirely within the right hemispatial field of the subject. In the left hemispatial condition, the opposite move was made. The subject's desk and chair were moved 42 cm. to the right so that the projection screen was entirely within the subject's left hemispatial field. In all spatial conditions subjects kept their heads centrally fixed with their noses pointing straight ahead, and deviated only their eyes toward the central fixation point on the projection screen. By these procedures, the hemispatial location of the stimulus presentation was manipulated independently from the VHFs. (Figures 5, 6, and 7 depict the three manipulations described above.)

The onset of each stimulus, both preexperimental and experimental, as well as the intertrial interval, were controlled manually by the experimenter. With the onset of a stimulus, a digital timer was activated which was stopped by the subject's release of a response key. This key was positioned directly in front of the subject, in line with the body's midline, and was released by the right or left index finger on go trials. On no-go trials, subjects withheld their response and the digital timer was reset by the release of a foot petal controlled by the experimenter. The slide duration of 50 msec. was controlled electronically by the linkage of the Polytechnic tachistoscope and a Gerbrantz shutter. Reaction time and error recordings were done by the experimenter.

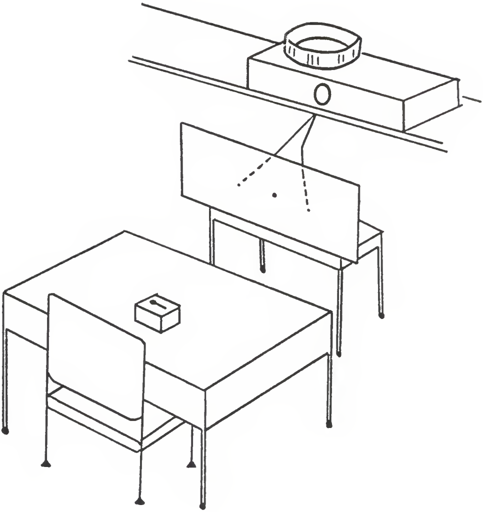

Figure 5. Central hemispatial condition where the LVF falls in left hemispace, and the RVF falls in right hemispace.

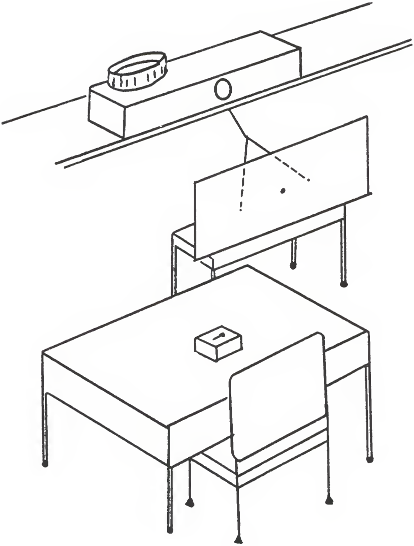

Figure 6. Right hemispatial condition where both the LVF and RVF fall entirely within right hemispace.

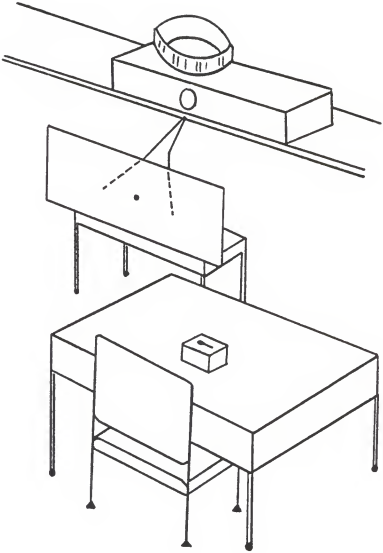

Figure 7. Left hemispatial condition where both the LVF and RVF fall entirely within left hemispace.

Procedure

For Experiments I and II, the subjects' tasks were to release a key with the left or right finger when a predesignated go stimulus was projected. There was no response made for no-go stimuli. Subjects were told to focus their eyes on the central fixation point and await stimulus presentations which appeared to the left or right of fixation.

Each subject in Experiments I and II participated in six sessions over a 2-week period. Each session involved a different set of stimuli from the six subsets previously described. Each hemispatial position, central, right, and left, was tested in two sessions,and this order was counterbalanced across subjects (see Appendix D).

All subjects first read and signed an informed consent form (see Appendices E and F). Each experimental session began with the preexperimental go-no-go RT task with the simple lights. The subject was given the bright or dim light as a go stimuli and performed 20 trials with the right hand and 20 trials with the left hand. Ten of these trials were go trials for each hand and they occurred in a random fashion. The hand and go stimuli designation were counterbalanced across subjects (see Appendix G).

The experimental condition consisted of 16 practice trials followed by four blocks of 40 trials each. Within each block of trials the go and no-go stimuli appeared in a randomized order, but an equal number of times. They also occurred equally as often in the RVF and LVF. After each block a 5-minute rest period was given,and between the second and third blocks the hand of response was changed.

These procedures allowed for all possible combinations of Hemispace, VHF, and Hand. These three factors were counterbalanced across subjects (see Appendix D).

Analyses

The data for each experiment consisted of RTs, in msec., and mean RTs for the various combinations of experimental factors were entered into the analyses. Excluded from this data were anticipation (RTs less than 50 msec.), omissions (RTs greater than 1000 msec.), and commissions (RT responses to the no-go stimuli). This error data was analyzed separately. Because intrinsic differences in motor agility between the left and right hands could disproportionately affect the direction of RTs, the RTs from the two hands to the preexperimental task were used as covariate values in the analyses of the experimental data.

Repeated - measures analyses of covariance were performed on the experimental data using the within-subjects factors being Hemispace (three levels: central, left, and right); Hand (two levels: left and right); and VHF (two levels: left and right). These analyses were performed over all four blocks of trials combined, and, because it was suspected that hemispatial effects could diminish over time, the four blocks of trials were also analyzed individually.

RESULTS

The results are presented separately for the verbal experiment, Experiment I, and the nonverbal experiment, Experiment II. The data from each experiment were analyzed using identical procedures. For both experiments, the mean reaction times, RTs, from go trials were compiled across all the combinations of Hemispace (left, center, right), Hand (left, right), and visual half field, VHF (left, right). The overall error rate for the go trials (anticipations + omissions/total number of go trials) was 3.9% in the verbal experiment and 3.8% in the nonverbal experiment. Therefore, the analyses of the go trials under the experimental conditions in the verbal and nonverbal experiments were based on 96.1% and 96.2% of the total trials respectively. Commission errors, that is responding on no-go trials, occurred more frequently. In the verbal experiment, 12% of the total no-go trials were incorrectly responded to, and in the nonverbal experiment there were commission errors on 15.7% of the total no-go trials. Analyses utilizing the Friedman's chi square (for ranks) revealed no significant differences in error rates for either the go or no-go trials between any of the experimental conditions for either experiment. (Table 1 summarizes this error data for the verbal experiment, and Table 2 summarizes the error data for the nonverbal experiment.)

Table 1

Summary of Friedman's Chi-Square Analyses of Error Data: Verbal Experiment

(a) Omission and anticipation errors for "go" trials in each of the experimental conditions of Hemispace, Hand, and VHF

Condition	Raw # errors	Rank summed	χ^2	ρ
Hemispace				
Left	114	34	.4	NS
Center	115	36		
Right	106	38		
Hand				
Left	159	25.5	.4	NS
Right	176	28.5		
VHF				
Left	170	27.5	.1	NS
Right	165	26.5		

(b) Commission errors for "no-go" trials in each of the experimental conditions of Hemispace, Hand, and VHF

Condition	Raw # errors	Rank summed	χ^2	ρ
Hemispace				
Left	311	34.5	2.6	NS
Center	343	35.5		
Right	390	38		
Hand				
Left	527	24	2.0	NS
Right	517	30		
VHF				
Left	474	29	.8	NS
Right	499	25		

Table 2

Summary of Friedman's Chi-Square Analyses of Error Data: Nonverbal Experiment

(a) Omission and anticipation errors for "go" trials in each of the experimental conditions of Hemispace, Hand, and VHF

Condition	Raw # errors	Rank summed	X^2	ρ
Hemispace				
Left	118	35	.2	NS
Center	101	35.5		
Right	110	37.5		
Hand				
Left	173	26.5	.1	NS
Right	156	27.5		
VHF				
Left	142	25	3.4	NS
Right	187	31		

(b) Commission errors for "no-go" trials in each of the experimental conditions of Hemispace, Hand, and VHF

Condition	Raw # errors	Rank summed	X^2	ρ
Hemispace				
Left	446	34.5	1.8	NS
Center	452	36.5		
Right	458	37		
Hand				
Left	686	26	.2	NS
Right	670	28		
VHF				
Left	714	30	2.0	NS
Right	642	24		

Experiment I: Analyses of Go RTs to Verbal Stimuli

The go RTs from the verbal experiment were initially analyzed using a repeated-measures analysis of covariance which incorporated all four blocks of trials together. (A summary of the results of this analysis is presented in Table 3.) A significant main effect was revealed for the VHF factor ($F_{1,17}=26.93$, $p<.0001$). Verbal stimuli delivered to the RVF resulted in significantly faster RTs than when delivered to the LVF. The mean RTs in the VHFs averaged across the Hemispace and Hand factors were RVF = 514.1 msec. and LVF = 528.7 msec. There were no other significant main effects or interaction effects among the experimental factors.

Because of the possibility that the effects of Hemispace or its interactions with other factors could attenuate over a short period of time or with practice, it was decided to use an analysis of covariance on each of the four blocks of trails separately. The summaries of these four analyses make up Tables 4, 5, 6, and 7. As was the case with the overall analysis, these separate analyses each showed only a significant VHF effect (block 1: $F_{1,17}=9.65$, $p<.0064$; block 2: $F_{1,17}=15.07$, $p<.0012$; block 3: $F_{1,17}=16.88$, $p<.0007$; block 4: $F_{1,17}=13.09$, $p<.0021$). In each case it was the RVF which resulted in faster RTs than the LVF. (The mean RTs and standard deviations for both VHFs averaged across Hemispace and Hand are shown in Table 8.)

Experiment II: Analyses of Go RTs to Nonverbal Stimuli

The go RT data from the nonverbal experiment were examined using the same sequence of analyses completed on the verbal data. First, a

Table 3

Summary of Analysis of Covariance of the Mean RTs from All Four Blocks of Trials in the Verbal Experiment

Source	df	SS	F	
Covariate	1	35250.3	2.39	-
Error	16	235809.1		
Hemispace	2	1134.9	0.42	-
Covariate	1	2833.4	2.10	-
Error	33	44586.7		
Hand	1	0.2	0.00	-
Covariate	1	1091.5	1.73	-
Error	16	10091.9		
Hemispace x Hand	2	46.0	0.04	-
Covariate	1	464.9	0.80	-
Error	33	19171.2		
VHF	1	11610.9	26.93	***
Error	17	7330.9		
Hemispace x VHF	2	162.5	0.44	-
Error	34	6300.6		
Hand x VHF	1	358.3	1.12	-
Error	17	5461.2		
Hemispace x Hand x VHF	2	192.8	0.33	-
Error	34	10005.6		

*$p<.05$.
**$p<.01$.
***$p<.001$.
- = not significant.

Table 4

Summary of Analysis of Covariance of the Mean RTs from Block 1 of the Verbal Experiment

Source	df	SS	F	
Covariate	1	28880.3	1.06	-
Error	16	288366.5		
Hemispace	2	4030.6	0.74	-
Covariate	1	2274.0	0.83	-
Error	33	90119.9		
Hand	1	690.9	0.09	-
Covariate	1	822.4	0.10	-
Error	16	127500.7		
Hemispace x Hand	2	5671.2	0.83	-
Covariate	1	1943.3	0.57	-
Error	33	113158.3		
VHF	1	12019.9	9.65	**
Error	17	21171.8		
Hemispace x VHF	2	109.7	0.06	-
Error	34	28956.1		
Hand x VHF	1	366.8	0.21	-
Error	17	29572.7		
Hemispace x Hand x VHF	2	2161.6	0.72	-
Error	34	50923.9		

*p<.05.
**p<.01.
***p<.001.
- = not significant.

Table 5

Summary of Analysis of Covariance of the Mean RTs from Block 2 of the Verbal Experiment

Source	*df*	*SS*	*F*	
Covariate	1	24627.7	1.47	-
Error	16	267215.3		
Hemispace	2	1191.4	0.27	-
Covariate	1	699.0	0.32	-
Error	33	72306.8		
Hand	1	1823.0	0.52	-
Covariate	1	97.2	0.03	-
Error	16	55766.1		
Hemispace x Hand	2	6742.1	2.27	-
Covariate	1	3802.2	2.56	-
Error	33	48984.4		
VHF	1	10827.6	15.07	***
Error	17	12210.8		
Hemispace x VHF	2	328.6	0.19	-
Error	34	29261.7		
Hand x VHF	1	306.9	0.27	-
Error	17	19262.3		
Hemispace x Hand x VHF	2	394.9	0.16	-
Error	34	14669.3		

*p<.05.
**p<.01.
***p<.001.
-= not significant.

Table 6

Summary of Analysis of Covariance of the Mean RTs from Block 3 of the Verbal Experiment

Source	df	SS	F	
Covariate	1	53692.9	3.06	-
Error	16	280379.9		
Hemispace	2	1385.2	0.39	-
Covariate	1	4048.7	2.30	-
Error	33	58033.8		
Hand	1	941.3	0.29	-
Covariate	1	230.9	0.07	-
Error	16	52430.7		
Hemispace x Hand	2	3958.2	0.71	-
Covariate	1	280.4	0.10	-
Error	33	91806.6		
VHF	1	10603.6	16.88	***
Error	17	10676.1		
Hemispace x VHF	2	4576.2	2.60	-
Error	34	29880.9		
Hand x VHF	1	3332.3	2.37	-
Error	17	23945.7		
Hemispace x Hand x VHF	2	79.2	0.06	-
Error	34	22025.9		

*$p<.05$.
**$p<.01$.
***$p<.001$.
- = not significant.

Table 7

Summary of Analysis of Covariance of the Mean TRs from Block 4 of the Verbal Experiment

Source	df	SS	F	
Covariate	1	37021.9	2.47	-
Error	16	240133.7		
Hemispace	2	6451.7	1.52	-
Covariate	1	5649.6	2.66	-
Error	33	70039.3		
Hand	1	1415.4	0.42	-
Covariate	1	6149.3	1.81	-
Error	16	54378.5		
Hemispace x Hand	2	4024.5	1.85	-
Covariate	1	7.5	0.01	-
Error	33	35948.6		
VHF	1	13076.0	13.09	**
Error	17	16976.5		
Hemispace x VHF	2	150.4	0.13	-
Error	34	20225.2		
Hand x VHF	1	267.6	0.33	-
Error	17	13653.7		
Hemispace x Hand x VHF	2	1908.5	0.88	-
Error	34	36689.5		

*$p<.05$.
**$p<.01$.
***$p<.001$.
- = not significant.

Table 8

Mean RTs by Blocks to the Verbal Stimuli Presented to the RVF and LVF, Averaged Across Hemispace and Hand Factors

	RVF		LVF	
	Mean RT (msec.)	S.D.	Mean RT (msec.)	S.D.
Block 1	535.9	62.7	550.9	59.8
Block 2	516.1	50.4	530.1	54.8
Block 3	507.5	53.3	521.6	55.9
Block 4	496.6	48.6	512.1	52.5

Note. Means are adjusted for covariate.

repeated-measures analysis of covariance was done which utilized all four blocks of data combined (Table 9). A significant covariate effect was found ($F_{1,16}$=11.92, $p<.0033$), which justifies the use of this procedure. (The means and standard deviations for the covariate values can be found in Table 10.) As was the case in the verbal experiment, there was a significant main effect for VHF ($F_{1,17}$=23.13, $p<.0002$); the direction, however, was reversed. Nonverbal stimuli presented in the LVF resulted in significantly faster RTs than when presented to the RVF. The mean RTs averaged across the Hemispace and Hand factors were LVF = 453.9 msec. and RVF = 481.9 msec.

Unlike the verbal experiment, however, there was also a significant Hand x VHF interaction effect ($F_{1,16}$=4.77, $p<.0432$). A Duncan's post hoc multiple comparison procedure revealed first that, for both the

Table 9

Summary of Analysis of Covariance of the Mean RTs from All Four Blocks of Trials in the Nonverbal Experiment

Source	df	SS	F	
Covariate	1	313184.5	11.92	**
Error	16	420515.9		
Hemispace	2	733.1	0.10	-
Covariate	1	13362.7	3.62	-
Error	33	121865.1		
Hand	1	810.6	1.59	-
Covariate	1	2.3	0.00	-
Error	16	8164.0		
Hemispace x Hand	2	554.1	0.35	-
Covariate	1	122.5	0.15	-
Error	33	26159.3		
VHF	1	42199.6	23.13	***
Error	17	31022.1		
Hemispace x VHF	2	1489.7	0.99	-
Error	34	25582.7		
Hand x VHF	1	1907.7	4.77	*
Error	17	6794.9		
Hemispace x Hand x	2			
VHF	34	399.2	0.63	-
Error		9160.2		

*$p<.05$.
**$p<.01$.
***$p<.001$.
- = not significant.

Table 10

Mean Covariate Values and Standard Deviations for the Nonverbal Experiment for Each Condition of Hemispace and Hand

Condition/Hand	Mean RT (msec.)	S.D.
Left hemispace/left hand	327.1	48.4
Left hemispace/right hand	332.2	48.2
Central hemispace/left hand	329.8	43.9
Central hemispace/right hand	327.1	40.2
Right hemispace/left hand	333.5	44.1
Right hemispace/right hand	339.4	50.3

left and right hands, responses to the nonverbal stimuli were significantly faster when the stimuli were projected into the LVF than to the RVF. This can be clearly seen in Figure 8, which depicts this interaction effect and simply reflects again the significant main effect found for VHF. A second finding from the post hoc test was that the hand producing the fastest RTs differed between the two VHFs. That is, when stimuli were presented in the LVF, it was the left hand which responded the quickest, whereas stimuli presented to the RVF were responded to quickest by the right hand. The absolute differences between the two hands within each VHF did not, however, reach significance. The means of this interaction and a summary of the Duncan's post hoc test of significance are presented in Table 11.

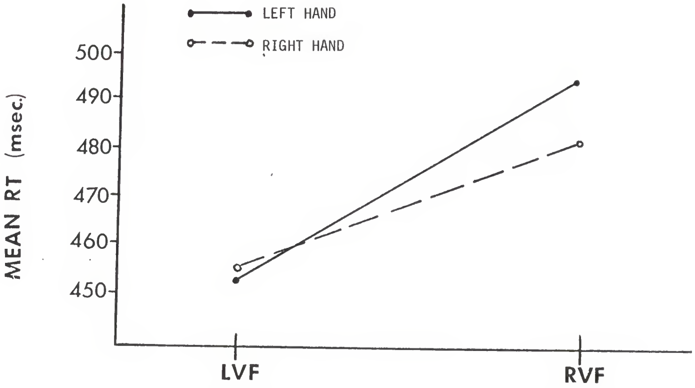

Figure 8. Mean RTs to nonverbal stimuli in the LVF and RVF by both hands. All blocks of trials combined.

Table 11

Duncan's Post Hoc Comparison for Mean Reaction Times for Each Combination of VHF and Hand for All Blocks Combined: Nonverbal Experiment

Ordered means	LVF/ left hand	LVF/ right hand	RVF/ right hand	RVF/ left hand
LVF/left hand (452.9)	-	2.0	24.0*	33.9*
LVF/right hand (454.9)	-	-	22.9*	31.9*
RVF/right hand (476.9)	-	-	-	9.9
RVF/left hand (486.8)	-	-	-	-

*$p<.05$ (two-tailed test of significance).

Individual analyses of covariance were also completed on each of the four blocks of trials separately. The summaries of these analyses appear in Tables 12-15. For all four blocks the covariate values were significant (block 1: $F_{1,17}=10.32$; $p<.0054$; block 2: $F_{1,17}=10.12$, $p < .0058$); block 3: $F_{1,17}=12.15$, $p<.0031$; block 4: $F_{1,17}=12.86$, $p< .0025$). (The means and standard deviation values for these covariates are the same as found in Table 10.)

Blocks 1 and 2 showed a significant main effect for VHF only (block 1: $F_{1,17}=19.83$, $p<.0003$; block 2: $F_{1,17}=12.15$, $p<.0028$). In both cases it was RTs to stimuli in the LVF which were significantly faster than those in the RVF. The means and standard deviations for

Table 12

Summary of Analysis of Covariance of the Mean RTs from Block 1 of the Nonverbal Experiment

Source	df	SS	F	
Covariate	1	210986.3	10.32	**
Error	19	326958.5		
Hemispace	2	1627.3	0.10	-
Covariate	1	12585.5	1.49	-
Error	33	279010.5		
Hand	1	219.3	0.04	-
Covariate	1	1871.1	0.32	-
Error	16	93423.4		
Hemispace x Hand	2	716.4	0.11	-
Covariate	1	6554.4	1.95	-
Error	33	110955.9		
VHF	1	51223.4	19.83	***
Error	17	43919.8		
Hemispace x VHF	2	133.6	0.04	-
Error	34	63096.8		
Hand x VHF	1	10.3	0.01	-
Error	17	27892.5		
Hemispace x Hand x VHF	2	3821.4	1.59	-
Error	34	40943.4		

*

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***

- = not significant.

Table 13

Summary of Analysis of Covariance of the Mean RTs from Block 2 of the Nonverbal Experiment

Source	df	SS	F	
Covariate	1	313020.9	10.12	**
Error	16	494686.8		
Hemispace	2	155.9	0.01	-
Covariate	1	4143.2	0.70	-
Error	33	196350.8		
Hand	1	5921.2	1.26	-
Covariate	1	1727.2	0.37	-
Error	16	75450.9		
Hemispace x Hand	2	14413.2	2.33	-
Covariate	1	9605.6	3.10	-
Error	33	102164.5		
VHF	1	36821.9	12.15	**
Error	17	51512.2		
Hemispace x VHF	2	13339.8	3.19	-
Error	34	70988.4		
Hand x VHF	1	3226.3	1.34	-
Error	17	40898.9		
Hemispace x Hand x VHF	2	3495.7	1.46	-
Error	34	40770.9		

*$p<.05$.
**$p<.01$.
***$p<.001$.
- = not significant.

Table 14

Summary of Analysis of Covariance of the Mean RTs from Block 3 of the Nonverbal Experiment

Source	df	SS	F	
Covariate	1	340001.8	12.15	**
Error	16	447594.6		
Hemispace	2	1479.9	0.21	-
Covariate	1	14161.7	4.03	-
Error	33	115919.2		
Hand	1	1236.6	0.22	-
Covariate	1	4065.9	0.72	-
Error	16	90383.5		
Hemispace x Hand	2	8153.6	1.16	-
Covariate	1	29506.7	8.42	**
Error	33	115680.7		
VHF	1	33920.2	13.08	**
Error	17	44097.3		
Hemispace x VHF	2	10082.5	4.27	*
Error	34	40149.3		
Hand x VHF	1	10812.0	9.98	**
Error	17	18422.2		
Hemispace x Hand x VHF	2	5313.9	1.88	-
Error	34	48076.3		

$^*p<.05$.
$^{**}p<.01$.
$^{***}p<.001$.
- = not significant.

Table 15

Summary of Analysis of Covariance of the Mean RTs from Block 4 of the Nonverbal Experiment

Source	df	SS	F	
Covariate	1	405264.6	12.86	**
Error	16	504178.0		
Hemispace	2	1335.3	0.15	-
Covariate	1	27833.3	6.33	**
Error	33	145059.3		
Hand	1	19841.6	8.03	**
Covariate	1	737.8	0.03	-
Error	16	39516.2		
Hemispace x Hand	2	10201.3	0.97	-
Covariate	1	2649.7	0.50	-
Error	33	173233.6		
VHF	1	48097.3	11.10	**
Error	17	73647.9		
Hemispace x VHF	2	13753.1	3.10	-
Error	34	75490.7		
Hand x VHF	1	114.9	0.06	-
Error	17	31075.3		
Hemispace x Hand x VHF	2	620.9	0.22	-
Error	34	48542.3		

*$p<.05$.
**$p<.01$.
***$p<.001$.
- = not significant.

the right and left VHF collapsed across Hemispace and Hand factors for blocks 1 and 2 appear in Table 16.

Table 16

Mean RTs and Standard Deviations for the LVF and RVF for Blocks 1 and 2 of the Nonverbal Experiment, Figures Collapsed Across the Hemispace and Hand Factors

	LVF		RVF	
	Mean RT (msec.)	*S.D.*	Mean RT (msec.)	*S.D.*
Block 1	454.1	78.2	484.9	74.3
Block 2	456.4	79.4	482.5	84.3

Block 3, summarized in Table 14, also showed this significant main effect for VHF ($\underline{F}_{1,17}$=13.08; $p<.0021$) with the LVF producing faster RTs (mean LVF=456.5; mean RVF=481.6). In addition, there were two significant interaction effects. First, there was a significant Hemispace x VHF interaction effect ($\underline{F}_{2,34}$=4.27, $p<.0222$), which is shown Figure 9. A Duncan's post hoc test of significance, summarized in Table 17, reveals that, although LVF presentation results in the fastest RTs in all three hemispatial conditions, this difference is only significant for the right hemispace condition. The LVF advantage for the nonverbal stimuli is not significant in either the left or central conditions.

Several views of this interaction were attempted to try and uncover a plausible explanation for this effect. Block 3 did have a

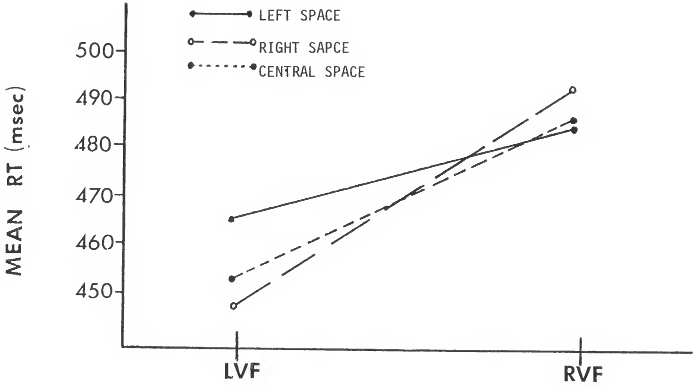


Figure 9. Mean RTs to nonverbal stimuli in the LVF and RVF in the three hemispatial conditions of left space, central space, and right space. Block three only.

Table 17

Duncan's Post Hoc Comparisons for Mean Reaction Times for each of the VHF and Hemispatial Conditions for Block 3 of the Nonverbal Experiment

	Right space	Central space	Left space	Left space	Central space	Right space
LVF-right space	-	6.1	18.7	28.5	29.1	43.0*
LVF-central space	-	-	12.1	21.9	22.5	36.4*
LVF-left space	-	-	-	9.8	10.4	24.3
RVF-left space	-	-	-	-	.6	14.6
RVF-central space	-	-	-	-	-	13.9
RVF-right space	-	-	-	-	-	-

*$\rho < .05$ (two-tailed test of significance).

unique feature. This was the block of trials which followed the change in the hand of response, either from left to right or from right to left. If this procedural change of hands systematically contributed to the VHF x Hemispace interaction effect found only in block 3, it could have been for one of three reasons: it could be due to the actual change of hands, to the initial effect of using a particular hand for a few trials, or to a learning-within hand effect. Each of these possibilities was examined by using a difference score to plot out RTs over the Hemispace and VHF factors.

If one hypothesized that the changing of hands was responsible for the Hemispace x VHF interaction, then the difference between the RTs from block 2 (one hand) to block 3 (the other hand) would be expected to clarify how these two factors differ across these blocks. An actual plot of these difference scores between these two blocks over the hemispatial conditions by VHF was, however, uninterpretable and showed no systematic pattern. Similarly, if it was the initial effect of using a particular hand for the first few trials, one might expect that a difference score from block 3 to block 1 would illuminate the unexpected Hemispace x VHF effect. Again, a plot of this difference score resulted in no such clarification. Finally, if learning occurred within a hand, then the differences in RTs from block 2 to block 1 and block 4 to block 3 would be expected to resolve the mysterious interaction effect. Again, this plot followed no systematic pattern with no clarification of the effect.

The second interaction effect which was significant was between the Hand and VHF factors ($\underline{F}_{1,17}=9.98$, $p<.0057$). Figure 10 shows that,

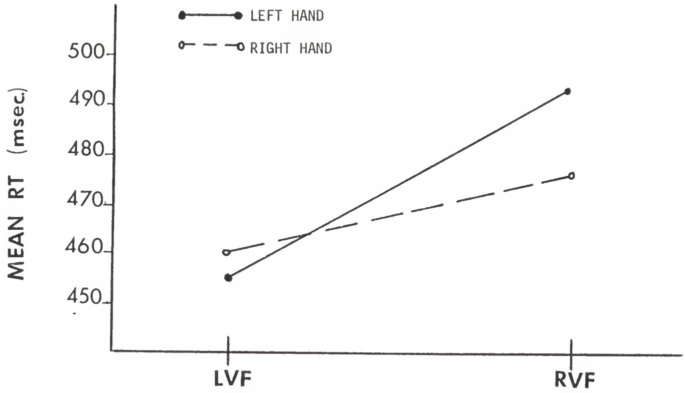


Figure 10. Mean RTs to nonverbal stimuli in the LVF and RVF by each response hand. Block 3 only.

again, the fastest RTs for both hands occurred in response to stimuli presented to the LVF. Duncan's post hoc procedures, however, revealed that this difference between the two VHFs was significant only when the left hand was used for the response. When the right hand was responding, the LVF did not produce significantly faster RTs than the RVF. The RT differences between the left and right hands within either the LVF or the RVF were also not significant. (Table 18 summarizes the means and tests of significance for this interaction.)

Table 18

Duncan's Post Hoc Comparisons for Mean Reaction Times for Each Combination of VHF and Hand for Block 3 of the Nonverbal Experiment

Ordered means	LVF/ left hand	LVF/ right hand	RVF/ right hand	RVF/ left hand
LVF/left hand (452.6)	-	7.9	18.8	39.2*
LVF/right hand (460.5)	-	-	10.9	31.3*
RVF/right hand (471.4)	-	-	-	20.4
RVF/left hand (491.8)	-	-	-	-

*$p<.05$ (two-tailed test of significance).

In block 4 the same significant VHF effect was found as reported for blocks 1, 2, and 3 ($\underline{F}_{1,17}$=11.10, ρ< .0039). This analysis is summarized in Table 15. The LVF (mean RT=448.7 msec.) was significantly faster than the RVF (mean RT=478.6 msec.). In addition, there was a significant main effect for Hand ($\underline{F}_{1,16}$=8.03, ρ<.0120), even with the covariate values considered. The right hand was significantly faster in responding (mean RT=453.7 msec.) than the left hand (mean RT=473.7 msec.).

The statistical procedures described above did not show significant main effects for the Hemispace factor. Therefore, an analysis was performed which simply examined the percentage of subjects which had their fastest RTs (collapsed across VHF and Hand) in each of the three hemispatial conditions. In the verbal experiment, 39% (7/18) of the subjects performed fastest in the right hemispace condition, 39% (7/18) were fastest in the central hemispace condition, and only 22% (4/18) were fastest in the left hemispace condition. This was diametrically the opposite for the nonverbal experiment, in which 39% (7/18) of the subjects performed fastest in the left hemispace condition, 39% (7/18) were fastest in the left hemispace condition, and only 22% (4/18) were fastest in the right hemispace condition. A $\underline{z}$ test for a significant difference between these proportions was not, however, significant.

DISCUSSION

Traditional VHF studies with verbal and nonverbal stimuli have resulted in lateral asymmetries which may be attributable to two hypotheses. First, the Direct Pathway Transmission model states that visual-field superiorities for verbal and nonverbal materials are due to direct anatomical connections between the contralateral visual field and the target hemisphere most capable of processing a particular type of information (Kimura, 1963, 1969, 1972). A second model implies that spatial, not anatomical, considerations are important. This Hemispatial model states that it is the relationship between the hemispatial location of the stimulus input and the targeted hemisphere which results in the observed lateral asymmetries (Bowers, Heilman, & Van Den Abell, 1981).

These two models set up opposing predictions for a paradigm such as the one used in this study where the hemispatial location of lateralized stimuli is varied. The Direct Pathway Transmission model emphasizes the importance of the VHFs. It predicts that a stimulus presented to the VHF which is contralateral to the hemisphere specialized to process it will be responded to quickest regardless of whether this VHF is located in the contralateral or ipsilateral hemispatial field. On the other hand, the Hemispatial model emphasizes hemispatial fields. It predicts that stimuli occurring in the hemispatial field contralateral to the target hemisphere will result in RT advantages which are independent of the VHF the information is projected to.

A third possibility suggested earlier in this writing considers both factors. It may be that observed laterality effects emerge because both anatomical and spatial mechanisms are involved. If so, one would then expect a type of compatibility effect such that information would be responded to quickest when it appeared in the VHF and the hemispatial field contralateral to the targeted hemisphere.

The results from Experiment I, which used verbal stimuli, supported only the Direct Pathway Transmission model. Verbal information, which the left hemisphere is specialized to process (in right handers), resulted in a RT advantage in the contralateral, RVF, regardless of which hemispatial field the information was received in. This visual-field effect was very robust (absolute RT differences between the VHFs of 18 msec.) and was evident in every combination of Hemispace and Hand.

Further analyses which examined the Hemispace, VHF, and Hand effects by blocks of trials did not change this result even though previous research suggested that Hemispace effects may be short lived and attenuate across trials. For example, Bowers et al. (1981) found a hemispace effect in their hemispace-VHF compatibility study which was observed only during the first half of each experimental session. Recall that this paradigm measured go-no-go RT responses to neutral light stimuli which were presented to left and right visual fields in central, left, and right hemispatial conditions. It was this evidence of an attenuation of the Hemispace effect which prompted the by-blocks analyses in this study.

In explaining the attenuation to the Hemispace effect, Bowers et al. (1981) suggested that each hemisphere may be specialized for attending to stimuli in the contralateral Hemispace (as suggested in the Hemispatial model), but only when there is a high probability that stimuli will occur randomly in either hemispatial field. When the probablity is high that there will be repetitive stimuli to one hemispatial field, as was the case in their study and the present study, they hypothesized that both hemispheres will "dynamically realign or refocus their attention to that side of space" (p. 762). If this is true, then the body midline will no longer act as the axis for dividing space into left and right halves, and the functional midline will have shifted.

Despite the intuitive logic of this argument, the individual analyses of the four blocks in the verbal experiment did not uncover any Hemispace effects, either in the early or the later blocks. Therefore it is difficult to address the possibility of a realignment of the body midline. It may be that other differences between the two paradigms can account for the lack of a Hemispace effect in the present study, and that when Hemispace effects are demonstrated they may indeed be short lived.

The results from the second experiment, which used nonverbal stimuli, were more complex. First, the analysis of variance for all blocks combined supported only the Direct Pathway Transmission model in that there was a significant VHF effect in the predicted direction. The line stimuli, hypothesized to be specifically mediated by the right hemisphere, were responded to significantly faster when projected to the LVF instead of the RVF. This significant VHF effect was again very robust (absolute RT difference between the two VHFs of 28 msec.), appearing in every combination of Hemispace and Hand. There was no apparent effect attributable to the Hemispace factor when all blocks of trials were analyzed together.

When the four blocks were analyzed separately, this picture changed in a curious fashion. The analyses of variance from blocks 1 and 2 mirrored the results from the overall analysis. The VHF effect was the only significant main effect and the direction was that predicted by the Direct Pathway Transmission model.

In block 3 a Hemispace x VHF interaction effect emerged, but it was not an interaction which was congruent with that predicted if both anatomical and spatial mechanisms were involved in laterality findings. Instead of observing the a priori interaction which predicted the fastest RTs to nonverbal stimuli to result from the LVF/left hemispace combination, in block 3 the fastest RTs came in response to stimuli projected to the LVF in right hemispace. In fact, left hemispace produced the slowest RTs, with the central condition falling between the two. These differences were not, however, significant and this effect disappeared by block 4.

It is difficult to interpret this phenomenon based on current theories of asymmetrical brain function. Remember that this effect was not clarified by examining it as a function of the procedural change of hands, a within-hand learning effect,or as an initial effect of using one hand for a few trials. Therefore it may be that the most conservative explanation of this finding is that it is a spurious effect.

Because it appeared and disappeared within one block (20 go trials) and reached only the .05 level of significance, it may be due to a statistical rather than a brain phenomenon.

There was also a significant Hand x VHF interaction effect found in the nonverbal experiment which was similar in pattern to that reported elsewhere in the literature (Berlucchi et al., 1971; Bowers et al., 1981; Swanson et al., 1978). That is, stimuli projected to one hemisphere were responded to more quickly by the hand controlled by that hemisphere, or the hand contralateral to that hemisphere. Specifically, LVF projections (to the right hemisphere) were responded to fastest by the left hand (controlled by the right hemisphere) and vice versa for RVF projections. This type of Hand x VHF interaction effect is also compatible with the Direct Pathway Transmission model. Because this model emphasizes that the anatomical hemisphere input-hemisphere output connnection is critical for laterality effects, it predicts that LVF stimuli will travel directly to the right hemisphere and will be responded to most rapidly by the left hand, which has its direct anatomical pathway from the right hemisphere. It is again curious that this VHF x Hand effect, which is significant in the overall analysis of variance, becomes significant only in block 3 of the by-blocks analyses.

To summarize briefly the findings related to the a priori hypotheses stated earlier, the results of these two experiments did not support the Hemispatial model of lateral asymmetries. The verbal experiment showed only a VHF effect across all analyses, which supports only the Direct Pathway Transmission model. The nonverbal experiment showed essentially the same support for this model with robust VHF effects, but also showed a Hemispace x VHF interaction effect which was not predicted by the Hemispatial model. It also resulted in a Hand x VHF interaction effect which was consistent with existing laterality literature.

When one is faced with findings which do not refute the null hypothesis, one cannot simply accept the null hypothesis as correct. It becomes necessary to investigate explanations for why the predicted results failed to appear, and to examine what could be done differently in a new attempt. In this case, several things come to mind.

One possibility is that the influence of a hemispatial factor may be modality specific. The one study which demonstrated a positive and significant effect for a hemispatial factor within a paradigm designed to engage one particular hemisphere used the tactile modality. Bowers and Heilman (1980) used a tactile line-bisection task where each subject used his hands to find the midpoint of a wooden stick. This type of task was believed to be more strongly mediated by the right hemisphere due to its tactuo-spatial demands. Their results fit best with the notion that both anatomical and hemispatial factors were important to observed laterality effects. That is, there was a significant interaction effect between the hand used and the hemispatial location the task was performed in. The most accurate performance was accomplished by the left hand (right hemisphere) when operating in left space. They concluded that, at least for the tactile modality, laterality effects stem from at least two factors, one being the anatomical connections between the hemisphere specialized for the task and the contralateral sensory channel or hand, and the other being some hemispatial mechanism involved in the perception and performance of activities in the hemispatial field contralateral to the targeted hemisphere.

The finding of modality-specific brain phenomena is, however, unusual. For example, the laterality effect itself has been demonstrated in the auditory modality (Berlin, 1977; Curry, 1967; Doehring, 1972; Gordon, 1974; Kimura, 1964, 1968, 1972; Levy, 1974, Milner, 1974; Morais & Bertleson, 1975; Studdert-Kennedy & Shankweiler, 1970), the visual modality (Bryden, 1965; Dee & Hannay, 1973; Dimond & Beaumont, 1974; Fontenot & Benton, 1972; Hellige, 1978; Hilliard, 1973; Klein et al. 1976; Rizzolatti et al., 1971; Springer, 1977; White, 1972; Zurif & Bryden, 1969), and the tactile modality (Benton et al., 1973; Benton et al., 1978; Gardner et al., 1976, 1977). This is true under a variety of conditions using a variety of stimuli and tasks. Since the Hemispatial model is hypothesized to account, at least in part, for these very laterality effects, the modality specificity notion is not an attractive one.

There have in fact been investigations of Hemispace in the visual modality, but the findings have been inconclusive. Recall that Bowers et al. (1981) found a Hemispace-VHF compatibility effect using lights presented to the left and right visual fields. Subjects responded quickest to LVF stimuli when the LVF fell into left hemispace. Similarly, RVF RTs were fastest when the RVF was within right hemispace. This suggested the importance of Hemispace as a factor in laterality effects, but it is not totally comparable to the present study since the stimuli used were not designed to specifically engage the processing of a particular hemisphere in a cognitive task.

More recently, an experiment was completed which investigated the contribution of hemispace using the visual modality and stimuli which were designed to engage the right hemisphere particularly (Streitfeld, 1983). In this study subjects were to discriminate between line segments of differing lengths and between dot patterns of differing densities. They performed these visuo-spatial tasks with the stimuli projected to the left and right visual fields when the two fields fell entirely within left hemispace and entirely within right hemispace. In this way the experiment was very similar to the present study. Like the findings reported here, this author also found no significant effects due to the hemispatial factor. Subjects performed these discrimination tasks most accurately when the stimuli were projected to the LVF, regardless of the hemispatial location of the visual fields.

One shared characteristic between the Streitfeld study and the present experiments is that hemispace was defined according to the body midline. Another recent idea which directly relates to hemispatial issues is the validity of this definition. In both these studies it was assumed that the body's midline acted as the reference for dividing spatial coordinates into left and right. This may be an inaccuracy or an incomplete definition. With the type of manipulation used here, the head and body axes are always aligned (subjects held their heads straight and deviated only their eyes to fixate). Therefore, there is no way to determine which axis is important (or whether both are important) in delineating hemispace. This was investigated by Bauer (1982) using a go-no-go RT paradigm with simple lights. Preliminary data suggest that manipulating only the position of the head does indeed influence RTs, especially for responses to RVF, left hemisphere stimulation.

Bauer (1982) has suggested that because the left hemisphere appears to be more affected by the head's position, it may map its output based on this coordinate system, whereas the right hemisphere maps its output with respect to the midline of the body. These initial findings await further verification over a larger number of subjects, but these initial implications for refining the manipulation to be used in future hemispatial studies are important.

One final variable which could be an important consideration for hemispatial effects is the distinction between attention and intention. Attention may be thought of as the selection and focusing on a particular stimulus (Pribram & McGuiness, 1975; Sokolov, 1963). In this way it may be more closely related to the perceptual characteristics of a stimulus or task. On the other hand, intention refers to a readiness to respond or act on a stimulus. It is more closely related to the behavioral aspects of the response. In the Bowers and Heilman (1980) study, which reported a significant hemispace effect, the task involved a tactile manipulation of the stimulus and may have involved more of an intentional component in the response. The present study and the one recently reported by Streitfeld (1983) found negative results with regard to the Hemispatial model, using tasks which required a more perceptual, selective-attentional response mode. Based on this kind of organization of the data, it may be that hemispatial effects depend to some degree upon a strong intentional component to the task.

It is not atypical to find at the end of a scientific investigation more intriguing questions than answers. This study has been no exception. The concept of a hemispatial factor influencing laterality effects commonly reported in the literature cannot be refuted based on the results of this study. It was not supported by these findings, but a failure to refute the null hypothesis is an incomplete test. Instead, several questions require further investigation. Is hemispace a modality-specific brain phenomenon? Does this mechanism come into operation only when a strong intentional component is involved in the performance of the task? Is it a factor which is short lived because the hemispheres can dynamically realign when stimuli are repeatedly delivered to only one hemispatial field? If so, could its effects be magnified by a paradigm which delivered stimuli to the visual fields within different hemispatial locations? Is the body axis the plane of reference which divides space into left and right? Is the axis of the head important? Are both reference points important depending upon the hemisphere stimulated? All of these questions justify further research.

While a few answers and these many questions constitute the main findings from this research, the data also provoked some interesting ideas which extend beyond the scope of the hemispace issue. Some time must be allocated to these findings since their implications for future research may stimulate as fruitful an endeavor as those previously mentioned. A comparison of the RT and error data between the two experiments reveals that the nonverbal task resulted in RTs which were between 50 and 100 msec. faster than those obtained in the verbal experiment. This holds true across the factors Hand, VHF, and Hemispace. Recall that the statistically significant VHF effects arose from a difference in magnitude of only 18-28 msec.! This large RT difference between the two tasks could be attributed to a number of differences between the two tasks, but several possibilities give rise to interesting notions.

Most obviously the nonverbal experiment may have been less complex, resulting in quicker RT responses. However, if one accepts that error rate may act as an indication of task difficulty, it would appear that the nonverbal task was in fact more difficult since the overall error rate in this experiment was 3.8% greater than for the verbal experiment. This issue of measuring complexity or task difficulty is a complex one to resolve or even assess. To attest to this consider the opposite argument that an increased error rate may reflect a less strict response criterion which would then result in both faster RTs and more errors! This question is not one which can be absolutely debated one way or the other from the results of this study, but, if one can put these difficult issues aside, some interesting hypotheses about this large RT discrepancy can be entertained.

Previous research has compiled considerable evidence that the right hemisphere is dominant for intention, or the preparation to act or respond (Heilman & Van Den Abell, 1979, 1980). For example, Heilman and Van Den Abell (1979) gave lateralized warning stimuli to normal subjects and measured the subsequent RTs to a central light stimulus. They found that warning stimuli projected to the right hemisphere reduced RTs of the right hand to a greater extent than warning stimuli projected to the left hemisphere reduced RTs of the left hand. And, importantly, warning stimuli projected to the right hemisphere reduced RTs of the right hand (controlled by the left hemisphere) even more than warning stimuli projected directly to its controlling left hemisphere. These findings supported the hypothesis of Heilman and Van Den Abell (1979), that the "right hemisphere attends to stimuli presented on both the right and left sides and also prepares both sides for action" (p. 319).

This notion that the right hemisphere is dominant for intention could underlie the large RT differences noted between the nonverbal and verbal experiments. The cognitive requirements of the nonverbal line-orientation task is designed to engage selectively the right hemisphere. This engagement may not be far removed from a lateralized warning, or it could be viewed from Kinsbourne's (1970a) notions that ongoing cognitive processing which involves a particular hemisphere will result in decreased RTs to stimuli which are projected laterally to the contralateral sensory input channel. Kinsbourne calls this a priming effect. If the line-orientation task activates the right hemisphere (primes it) and the right hemisphere is also dominant for intention, or preparation for actions on both sides, then this overall reduction of RTs in the nonverbal task is predictable.

Of course, a systematic investigation of this idea is necessary to evaluate its validity, and such an investigation would be fraught with difficulties like the equalization of task complexity mentioned previously. Nonetheless, the notion is provocative and has yet to be examined.

A less than exhaustive search of the literature reporting laterality tasks which utilized both verbal and nonverbal tasks and used RTs as the response measure has not illuminated the issue to any extent.

This further underscores the necessity of a systematic approach designed specifically to answer this question.

For example, large RT differences have been reported between verbal and nonverbal tasks which are in the opposite direction of the one noted here (Rizzolatti et al., 1971). That is, verbal stimuli resulted in faster RTs. Further, this superiority of the verbal task was also accompanied by fewer errors. Again, it cannot be emphasized enough that these examples do not in any way attempt to equate task complexity and difficulty, and therefore a critical analysis of their results cannot determine the theoretical viability of the idea that a nonverbal task could engage the intentional dominance of the right hemisphere, and thereby induce an overall RT reduction.

An investigation of this idea will require not only an equalization of tasks, but also a careful analysis and interpretation of errors as they reflect the subject's response criteria.

APPENDIX A
THE HANDEDNESS INVENTORY

Indicate hand preference:	Always left	Usually left	No preference	Usually right	Always right
1. To write a letter legibly					
2. To throw a ball to hit a target					
3. To play a game requiring the use of a racquet					
4. At the top of a broom to sweep dust from the floor					
5. At the top of a shovel to move sand					
6. To hold a match when striking it					
7. To hold scissors to cut paper					
8. To hold thread to guide through the eye of a needle					
9. To deal playing cards					
10. To hammer a nail into wood					
11. To hold a toothbrush while cleaning teeth					
12. To unscrew the lid of a jar					

Source. Briggs and Nebes, 1975.

APPENDIX B
EXPERIMENT I: VERBAL STIMULI

SET 1	Nouns	Verbs
	CHIN	PUSH
	DIRT	TAKE
	TANK	JUMP
	LIME	POUR
	LAWN	WASH
	VEST	TOSS
	CANE	PULL
	TOMB	CHEW

SET 2	Nouns	Verbs
	DOVE	PUSH
	LIMB	GIVE
	MONK	JUMP
	JAIL	POUR
	FORK	WASH
	LUMP	HIRE
	CLAW	LOOK
	OVEN	DROP

SET 3	Nouns	Verbs
	FROG	TOSS
	CORD	SWIM
	LARK	HOLD
	MULE	BAKE
	JURY	PULL
	MAST	OPEN
	HARP	BITE
	FOWL	GRAB

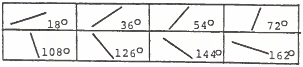
SET 4	Nouns	Verbs
	CHIN	TAKE
	MONK	JUMP
	DIRT	WASH
	CANE	PULL
	VEST	KICK
	JAIL	YELL
	LUMP	LOOK
	CLAW	DROP

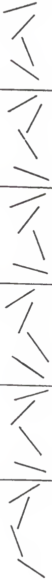
SET 5	Nouns	Verbs
	TANK	PUSH
	LIME	TOSS
	DOVE	CHEW
	TOMB	SKIP
	OVEN	HIRE
	CORD	TALK
	JURY	HOLD
	MAST	OPEN

SET 6	Nouns	Verbs
	LAWN	POUR
	LIMB	SING
	FORK	GIVE
	FROG	SWIM
	LARK	BAKE
	MULE	STIR
	HARP	BITE
	FOWL	GRAB

APPENDIX C
EXPERIMENT II: NONVERBAL STIMULI

LINES





	LINE	ANGLE	GO or NO-GO
SET 1		18	GO
		54	NO-GO
		108	GO
		144	NO-GO
SET 2		36	GO
		72	NO-GO
		126	GO
		162	NO-GO
SET 3		18	NO-GO
		54	GO
		108	NO-GO
		162	GO
SET 4		36	GO
		72	NO-GO
		126	GO
		144	NO-GO
SET 5		18	NO-GO
		54	GO
		126	NO-GO
		162	GO
SET 6		36	NO-GO
		72	GO
		108	NO-GO
		144	GO

APPENDIX D
DESIGNATION FOR HEMISPATIAL AND HAND VARIABLES ACROSS THE SIX SESSIONS

		SESSION and STIMULI SET NUMBER					
		1	2	3	4	5	6
Subjects 1,7& 13	HAND block 1/2	L/R	R/L	L/R	R/L	L/R	R/L
	HEMISPACE	L*	C**	R***	L	C	R
Subjects 2,8& 14	HAND block 1/2	L/R	R/L	L/R	R/L	L/R	R/L
	HEMISPACE	C	R	L	C	R	L
Subjects 3,9& 15	HAND block 1/2	L/R	R/L	L/R	R/L	L/R	R/L
	HEMISPACE	R	L	C	R	L	C
Subjects 4,10& 16	HAND block 1/2	R/L	L/R	R/L	L/R	R/L	L/R
	HEMISPACE	L	C	R	L	C	R
Subjects 5,11& 17	HAND block 1/2	R/L	L/R	R/L	L/R	R/L	L/R
	HEMISPACE	C	R	L	C	R	L
Subjects 6,12& 18	HAND block 1/2	R/L	L/R	R/L	L/R	R/L	L/R
	HEMISPACE	R	L	C	R	L	C

*L= Left **C= Central ***R= Right

APPENDIX E
CONSENT FORM: NONVERBAL

Subject's Name____________________ Address________________

Project #________ Project Title Reaction Times to Visuospatial Stimuli

Principle Investigators Heilman/Bowers Date______________

I agree to participate in the research as explained to me below:

The purpose of this study is to see how rapidly you can respond to particular lines flashed on a screen. The task will involve releasing a response key with either your left or right hand whenever a target line flashes on. You will sit at a table with your left or right hand placed on a response key. You will be asked to focus your eyes on a small green light that is located in the middle of a screen. Out to the sides of the screen are the various lines to be responded to. When one of the target lines flashes on, you are to release the response key as quickly as possible. You will be told at the beginning of the session which hand you are to use, and which lines you are to respond to. What is extremely important is for you always to keep your eyes fixated on the green light. Even when one of the lines flashes on, still keep your eyes focused on the green light.

You will participate in six testing sessions, given one day apart. Each session will last for approximately 45 minutes. During two sessions, the screen with the lines will be placed directly in front of you. During the other four seesions, the screen will be placed slightly to the right or slightly to the left.

This experiment does not involve any painful or aversive stimuli. After the sessions are over, we will explain to you in more detail why we were interested in having you do this task. If you are interested in our results, contact us next semester after they have been analyzed.

The above stated nature and purpose of this research, including discomforts and risks involved (if any) have been explained to me verbally by ____________________________. Furthermore, it is agreed that the information gained from this investigation may be used for educational purposes which may include publication. I understand that I may withdraw my consent at any time without prejudice. In the event of my sustaining a physical injury which is proximately caused by this experiment, no professional medical care will be provided me without charge.

Signed________________________

I have defined and fully explained this research to the participant whose signiture appears above.

Signed________________________

APPENDIX F
CONSENT FORM: VERBAL

Subject's Name______________________________Address__________________

Project #________ Project Title__Reaction Times to Verbal Stimuli_______

Principle Investigators Heilman/Bowers___________ Date_________________

I agree to participate in the research as explained to me below:

The purpose of this study is to see how rapidly you can respond to a word that is briefly flashed on a screen. The words will occur in various locations on the screen which will be located in front of you on a table. Your task will be to release a response key with either your left or right hand whenever a particular word is flashed on the screen. You will sit at a table with on hand placed on a response key. You will be asked to focus your eyes on a small green light that is located in the middle of the screen. Words will flash on in various positions out to the side of the screen. When a particular word comes on, this will indicate that you are to respond with your hand. When another particular word comes on this will indicate that you are not to respond with your hand. You will be told at the beginning of a session, which words you are to respond to by releasing the key an which words indicate no response. What is extremely important is that you always keep your eyes fixated on the green light. Even when a word blinks on, keep your eyes fixated on the green light.

You will participate in six testing sessions, given one day apart. Each session will last approximately 45 minutes. During two sessions, the screen will be placed directly in front of you. During the other sessions the screen will be placed slightly to your left or slightly to your right.

This experiment does not involve any painful or aversive stimuli. After the sessions are over, we will explain to you in more detail why we are interested in having you do this task. If you are interested in the results of this study, contact us at the beginning of next semester.

The above stated nature and purpose of this research , including discomforts and risks involved (if any) have been explained to me verbally by ________________, Furthermore, it is agreed that the information gained from this investigation may be used for educational purposes which may include publication. I understand that I may withdraw my consent at any time without prejudice. In the event of my sustaining a physical injury which is proximately caused by this experiment, no professional medical care will be provided me without charge.

signed__________________________

I have fully define and explained this research to the participant whose signiture appears above.

signed__________________________

APPENDIX G
PREEXPERIMENTAL "GO-NO-GO" RT TASK WITH HAND AND "GO" STIMULI DESIGNATIONS

		SESSION NUMBER					
		1	2	3	4	5	6
Subjects 1,5,9,13,& 17	HAND	R*/L**	L/R	R/L	L/R	R/L	L/R
	GO Stimuli	B***	D****	B	D	B	D
Subjects 2,6,10,14& 18	HAND	L/R	R/L	L/R	R/L	L/R	R/L
	GO Stimuli	B	D	B	D	B	D
Subjects 3,7,11,& 15	HAND	R/L	L/R	R/L	L/R	R/L	L/R
	GO Stimuli	D	B	D	B	D	B
Subjects 4,8,12,& 16	HAND	L/R	R/L	L/R	R/L	L/R	R/L
	GO Stimuli	D	B	D	B	D	B

*R= Right
**L= Left

***B= Bright
****D= Dim

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BIOGRAPHICAL SKETCH

Cathy Suzanne Williams was born January 25, 1955, in Oklahoma City, Oklahoma. At the age of two, she moved to Florida where she attended schools in Fort Lauderdale, and graduated in the top 5% of her senior class at Stranahan High School in June 1972. At Stranahan High School she met her future husband, and they were married, also in 1972. She attended Broward Community College, where in 1974 she received the degree of Associate of Arts, and Florida Atlantic Unviersity, where in 1976 she was awarded the degree of Bachelor of Arts with highest honors. She continued her studies at Florida Atlantic University until 1979 and received the degree of Master of Arts with a major in experimental psychology in 1980. In 1979 she and her husband and their two children moved to Gainesville, Florida, where she began doctoral studies in clinical psychology at the University of Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Kenneth M. Heilman

Kenneth M. Heilman, Chairman
Professor of Neurology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Eileen B. Fennell

Eileen B. Fennell
Associate Professor of Clinical Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Russell M. Bauer

Russell M. Bauer
Assistant Professor of Clinical Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dawn Bowers

Dawn Bowers
Assistant Professor of Neurology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Paul J. Jensen

Paul J. Jenson
Professor of Speech

This dissertation was submitted to the Graduate Faculty of the College of Health Related Professions and to the Graduate School, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 1984

Dean, College of Health Related Professions

Dean for Graduate Studies and Research